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EFFECTS OF CANOPY GEOMETRY ON THE DRAG COEFFICIENT OF A CROSS PARACHUTE IN THE FULLY OPEN AND REEFED CONDITIONS FOR A W/L RATIO OF 0.264

By
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13. ABSTRACT

This report describes a series of wind-tunnel tests on the cross-type parachute. The effects of cloth permeability, number of suspension lines, and suspension line length were investigated. Forty-inch-diameter models with a canopy arm width-to-length ratio (W/L) of 0.264 were tested at various velocities from 50 fps to 300 fps in the fully inflated state. Results of these tests demonstrate that the parachute geometry does have an effect on the drag capability of the cross parachute. Additional tests of reefed configurations for several reefing line lengths-to-canopy-diameter ratios from 0.45 to 1.6 at a constant velocity of 275 fps established the reefed characteristics of this parachute. Data are presented in tabular and graphical format. Photographs of representative canopy shapes are included for illustration.

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Effects of Canopy Geometry on the Drag Coefficient of a Cross Parachute in the Fully Open and Reefed Conditions for a W/L Ratio of 0.264

The investigation presented in this report is related to the improvement of parachute technology.

ROBERT ENNIS
Captain, USN
Commander

V. C. D. DAWSON
By direction

CONTENTS

ILLUSTRATIONS

Figure

Figure

Figure

TABLES

REFERENCE

1 AFFDL, AIRFORCESYSCOM, "Drag and Stability of Cross Type Parachutes," FDL-TDR-64-155, Feb 1965

SYMBOLS

D	drag force, lbs
C_D	coefficient of drag
V	velocity, ft/sec
ρ	density of air, slugs/ft^3
q	dynamic pressure, lbs/ft^2
So	canopy reference area, ft^2
L	length of canopy arm
W	width of canopy arm
l	length of reefing line
W/L	canopy arm width-to-length ratio
l/L	reefing line length-to-canopy-diameter ratio

DEFINITIONS

Permeability	rate of airflow through cloth in ft^3/ft^2-min when measured under a pressure differential of 1/2 inch of water.
Skirt Reefing	a restriction of the skirt of a drag-producing surface to a diameter less than its diameter when it is fully inflated.
Percent Reefed	ratio of the drag force produced in the reefed condition to the drag force of the fully inflated parachute.

INTRODUCTION

Limited supersonic wind-tunnel tests at Mach numbers of M=1.6, 1.8, 2, and 3.2 demonstrated that the cross-type parachute has positive inflation with predictable aerodynamic drag and very good stability characteristics. This, together with very good subsonic aerodynamic stability and drag efficiency, and a low infinite mass opening shock factor, indicates that the cross parachute can be a very useful high-performance decelerator. The basic simplicity of the design should allow for some reduction in cost compared to equivalent ribbon and ring slot configurations, provided similar manufacturing tolerances are applicable.

1. The problem areas which have been encountered with the cross parachute are:

   a. Lack of good definition of the drag coefficient

   b. Absence of data on the reefed canopy characteristics

Heinrich, in reference (a), investigated the effects of cloth effective porosity, arm width-to-length ratio (W/L), and angle of attack on the static stability and drag coefficients of the cross parachute. Experience with the cross parachute indicates that additional parameters, other than those considered in reference (a), affect the drag-producing capability of this design, namely, the number of suspension lines, suspension line length, and velocity.

2. The purposes of this investigation are:

   a. To determine the effects of geometric configuration on the drag coefficient of a cross parachute having an arm width-to-length ratio of 0.264. The parameters investigated are cloth permeability, number of suspension lines, suspension line length, and velocity.

   b. To establish the percent reefing of the various parachute configurations as a function of reefing line length to canopy arm length ratio.

APPROACH. Three series of model cross parachutes were designed using a canopy cloth of different air permeability for each series. All models consisted of two panels 40 inches in length with a W/L = 0.264. The two panels were arranged to form the configurations

illustrated in Figure 1. Each series of models consisted of three parachutes with 8, 16, and 24 suspension lines, respectively, for the same canopy cloth. As initially installed, the suspension lines were 1.8 canopy diameters in length. These lines were later shortened to 1.6 and 1.4 canopy diameters. This approach provided 27 possible geometric configurations for drag coefficient studies. Installation of reefing rings in the skirt hem provided an additional 27 reefed parachute configurations. Parachute construction details are illustrated in Figure 2 and the materials used in construction of the models are enumerated in Table I.

3. The wind-tunnel tests were conducted at the University of Maryland 7-foot x 11-foot cross section Subsonic Wind Tunnel at College Park, Maryland. The wind-tunnel support system, Figure 3, was designed to position the model canopies. A guide tube along the wind-tunnel center line permitted the control of parachute oscillations. To maintain a relatively aerodynamically uncluttered test section, guy wires were used to support the guide tube. In all tests, the parachute suspension lines were attached to the support ring of an aerodynamic drag force sensing device. Assembly in this manner lengthened the suspension lines of the various canopies to the required length. Each parachute was mounted on the support system, and measurements of the drag force were made at various wind-tunnel velocities from 50 fps through 300 fps. Reefing lines of 1/16-inch diameter flexible steel cable were then installed, and measurements of the drag force in the reefed configuration were made for several reefing line length-to-canopy-diameter ratios from 0.45 through 1.6. Upon completion of these tests, the parachute suspension lines were shortened to the next test length and the measurement procedures repeated.

4. Test data were reduced to coefficient form by means of the following formulae:

$$C_D = \frac{D}{qSo}$$

$$q = 1/2\ \rho\ V^2$$

$$So = 2LW - W^2$$

$$\% \text{ reefed} = \frac{\text{Drag of parachute in reefed condition at velocity V}}{\text{Drag of fully opened parachute at same velocity}}$$

5. The reference area of all parachute models used in this test is 5.092 ft^2.

RESULTS

The experiments documented in this report have established the drag coefficients and reefed parachute characteristics for the cross parachute (W/L = 0.264) for various combinations of velocity, cloth permeability, suspension line length, number of suspension lines, and hem reefing line length. Of the three series of parachutes which were tested, meaningful data were obtained only on the number 2 and number 3 series canopies. Data from the series number 1 parachutes (cloth permeability of 8 ft^3/ft^2 min)were very limited due to the induced canopy rotation which resulted in the canopy spinning closed around the guide tube support system. Low cloth permeability appears to be another cause of canopy rotational instability. Series number 2 and number 3 (cloth permeability of 80 ft^3/ft^2 min and 208 ft^3/ft^2 min, respectively) remained fully open throughout the velocity test range. Drag coefficient data for the various fully opened configurations of the number 2 and number 3 series parachutes are tabulated in Tables II and III and graphically presented in Figures 4 and 5, respectively. These data show that for any given configuration, the lower permeability series number 2 parachutes have a higher drag coefficient than the series number 3. In all configurations, an increase in the suspension line length or the number of suspension lines was accompanied by an increase in drag coefficient. The drag coefficients of the eight suspension line canopies are essentially constant over the velocity range tested. An increase in the number of suspension lines not only raises the magnitude of the drag coefficient, but also produces a drag rise with increasing velocity. There is a strong indication that the drag coefficient rises sharply at velocities less than 40 fps. An example of this effect is shown in Figure 44, Appendix A. The range of drag coefficients for the tested configurations varied from a minimum of 0.54 to a maximum of 0.75. Photographs of the fully inflated parachutes at wind-tunnel velocities of 50, 100, and 200 fps are presented in Figures 6 through 23. All parachutes were reefed using a 1/16-inch diameter flexible steel cable. Data were obtained for ratios of reefing line length-to-canopy-diameter of 0.45, 0.7, 0.85, 1.0, 1.15, and 1.6. These data are tabulated in Tables IV and V and graphically represented in Figures 24 and 25. Since the drag of the fully inflated parachute increases as the number and/or length of suspension lines increases, the percent reefed for a given reefing line length-to-canopy-diameter ratio is reduced.

TABLE I

MATERIALS USED IN MODEL PARACHUTE CONSTRUCTION

ITEM	MATERIAL	PARACHUTE SERIES		
		NUMBER 1	NUMBER 2	NUMBER 3
1	CLOTH	MIL-C-7020, TYPE I HEAT SET, AIR PERMEABILITY 8 $FT^3/FT^2/MIN$ @ 1/2 INCH WATER PRESSURE DIFFERENTIAL	MIL-C-7020, TYPE I	4.75 $OZ./YD^2$, DOBBY WEAVE, AIR PERMEABILITY 208 $FT^3/FT^2/MIN$ @ 1/2 INCH WATER PRESSURE DIFFERENTIAL
2	TAPE	MIL-T-5038, TAPE III, 1/2 INCH WIDE	MIL-T-5038, TYPE III, 1/2 INCH WIDE	MIL-T-5038, TYPE III, 1/2 INCH WIDE
3	SUSPENSION[1] LINE	MIL-C-17183	MIL-C-17183	MIL-C-17183
4	STITCHES[2]	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, 2 ROWS ON 1/4 INCH NEEDLE GAUGE.		
5	STITCHES	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, SINGLE ROW		

[1] 8 SUSPENSION LINE CANOPIES USE, TYPE VI, 500 LB TENSILE STRENGTH
16 SUSPENSION LINE CANOPIES USE, TYPE IV, 300 LB TENSILE STRENGTH
24 SUSPENSION LINE CANOPIES USE, TYPE III, 200 LB TENSILE STRENGTH

[2] ALL THREAD, V-T-295. TYPE I OR II, CLASS 1 OR 2, SIZE B

TABLE II

DRAG COEFFICIENT TEST DATA; PARACHUTE SERIES NO. 2

VELOCITY V	DYNAMIC PRESSURE q	DRAG COEFFICIENT								
		8 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
		SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
		1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L
50	2.973	0.540	0.632	0.604	0.561	0.620	0.620	0.595	0.645	0.670
75	6.689	0.566	0.611	0.610	0.577	0.629	0.646	0.587	0.645	0.680
100	11.892	0.568	0.625	0.635	0.580	0.624	0.677	0.598	0.661	0.704
125	18.582	0.560	0.627	0.638	0.589	0.644	0.681	0.603	0.682	0.721
150	26.758	0.566	0.627	0.641	0.605	0.667	0.694	0.613	0.700	0.738
175	36.420	0.568	0.629	0.637	0.603	0.672	0.701	0.626	0.704	0.749
200	47.569	0.570	0.633	0.645	0.613	0.679	0.715	0.638	0.714	0.757
225	60.602	0.566	0.627	0.642	0.617	0.685	0.724	0.641	0.715	0.762
250	74.327	0.568	0.631	0.650	0.616	0.692	0.730	0.651	0.726	0.775
275	89.936	0.570	0.633	0.645	0.624	0.695	0.732	0.658	0.729	0.774
300	107.031	0.568	0.615	0.654	0.625	0.698	0.733	0.662	0.729	0.779

TABLE III

DRAG COEFFICIENT TEST DATA; PARACHUTE SERIES NO. 3

VELOCITY V	DYNAMIC PRESSURE q	DRAG COEFFICIENT								
		8 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
		SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
		1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L
50	2.973	0.599	0.699	0.708	0.570	0.645	0.696	0.624	0.687	0.696
75	6.689	0.598	0.670	0.654	0.594	0.650	0.677	0.599	0.683	0.685
100	11.892	0.588	0.646	0.650	0.583	0.645	0.686	0.599	0.669	0.712
125	18.582	0.588	0.636	0.660	0.586	0.652	0.692	0.608	0.685	0.709
150	26.758	0.587	0.645	0.661	0.585	0.662	0.693	0.612	0.679	0.724
175	36.420	0.586	0.635	0.659	0.580	0.659	0.700	0.616	0.688	0.727
200	47.569	0.585	0.634	0.655	0.589	0.665	0.709	0.618	0.701	0.734
225	60.602	0.584	0.630	0.656	0.593	0.668	0.706	0.625	0.702	0.734
250	74.327	0.583	0.634	0.656	0.605	0.671	0.712	0.632	0.710	0.738
275	89.936	0.584	0.634	0.657	0.617	0.677	0.717	0.639	0.715	0.741
300	107.031	0.584	0.637	0.659	0.623	0.679	0.722	0.645	0.722	0.745

TABLE IV

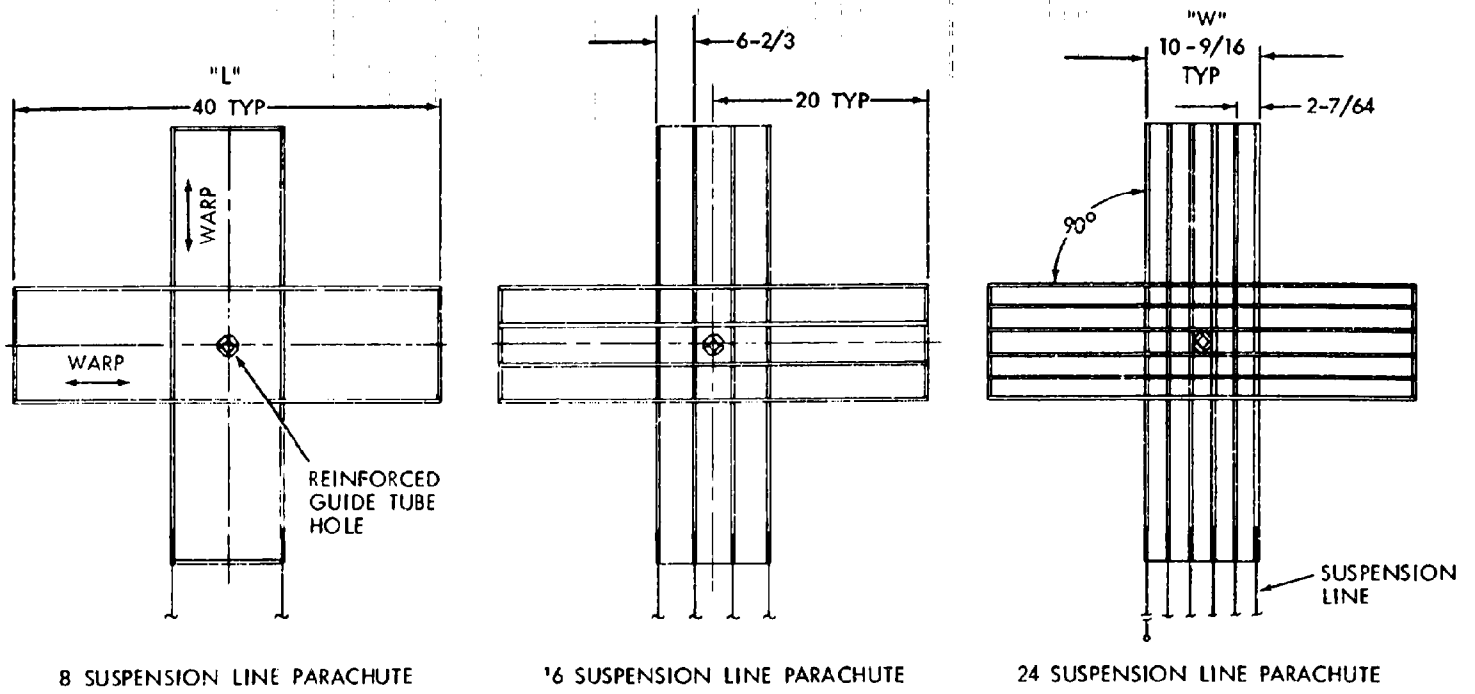
REEFED CANOPY TEST DATA; PARACHUTE SERIES NO. 2
TEST VELOCITY - 275 FPS

REEFING LINE LENGTH / CANOPY DIAMETER $\frac{\ell}{L}$	PERCENT REEFED								
	8 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
	SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
	1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.3 L
1.60	98.1	96.4	94.0	96.8	88.6	84.2	93.8	85.1	80.9
1.30	85.9	78.8	76.3	81.1	74.2	69.1	75.7	69.0	65.5
1.15	80.5	73.1	71.0	72.3	65.5	62.6	67.9	61.6	58.7
1.00	72.5	66.6	64.8	64.7	58.3	55.6	61.1	55.0	52.3
0.85	61.8	54.0	52.7	56.3	50.4	48.2	54.1	48.3	46.0
0.70	46.1	40.6	40.0	44.6	40.9	38.5	44.8	39.3	37.1
0.45	31.5	27.6	26.4	26.6	23.7	24.0	26.3	22.9	21.4

TABLE V

REEFED CANOPY TEST DATA; PARACHUTE SERIES NO. 3
TEST VELOCITY = 275 FPS

REEFING LINE LENGTH / CANOPY DIAMETER $\frac{\ell}{L}$	PERCENT REEFED								
	8 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
	SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
	1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L	1.0 L	1.4 L	1.8 L
1.60	97.8	97.8	94.7	99.5	90.8	86.5	96.1	87.0	83.4
1.30	87.0	78.9	77.4	83.0	74.4	70.4	78.2	69.9	67.6
1.15	81.1	71.1	71.1	73.9	66.6	63.7	70.1	63.0	61.1
1.00	70.7	61.7	63.8	64.5	58.3	56.2	62.3	55.8	54.4
0.85	52.7	48.7	47.4	54.6	49.5	43.3	53.5	48.0	46.8
0.70	40.5	37.1	36.8	43.1	38.4	37.9	43.8	39.2	38.7
0.45	28.1	16.2	16.0	22.7	21.0	20.2	23.6	21.3	21.5

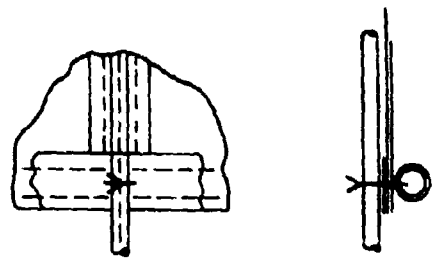


8 SUSPENSION LINE PARACHUTE

16 SUSPENSION LINE PARACHUTE

24 SUSPENSION LINE PARACHUTE

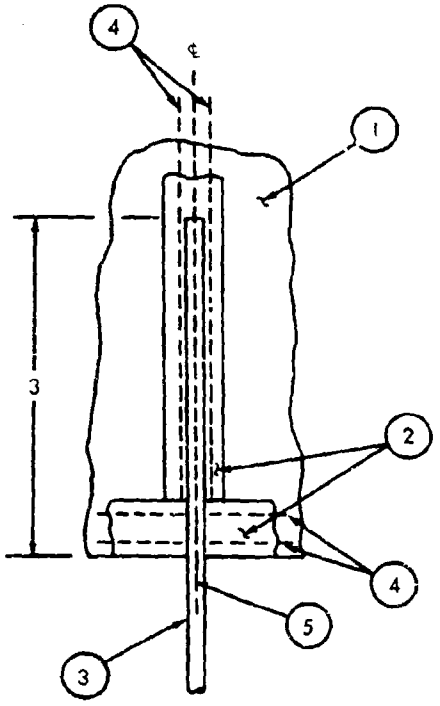
FIG. 1 MODEL PARACHUTE CONFIGURATIONS–CONSTRUCTION DETAILS ARE SHOWN IN FIG. 2



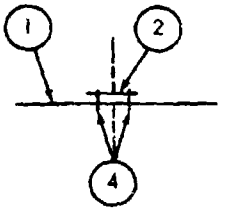
REEFING RING TIE CORD

REEFING RING

1/4 O.D. x 3/16 I.D. x 1/8 LONG



SKIRT HEM - SUSPENSION LINE ASS'Y



TYPICAL TAPE - CANOPY CROSS SECTION

FIG. 2 MODEL PARACHUTE CONSTRUCTION DETAILS
SEE TABLE I FOR MATERIALS IDENTIFICATION

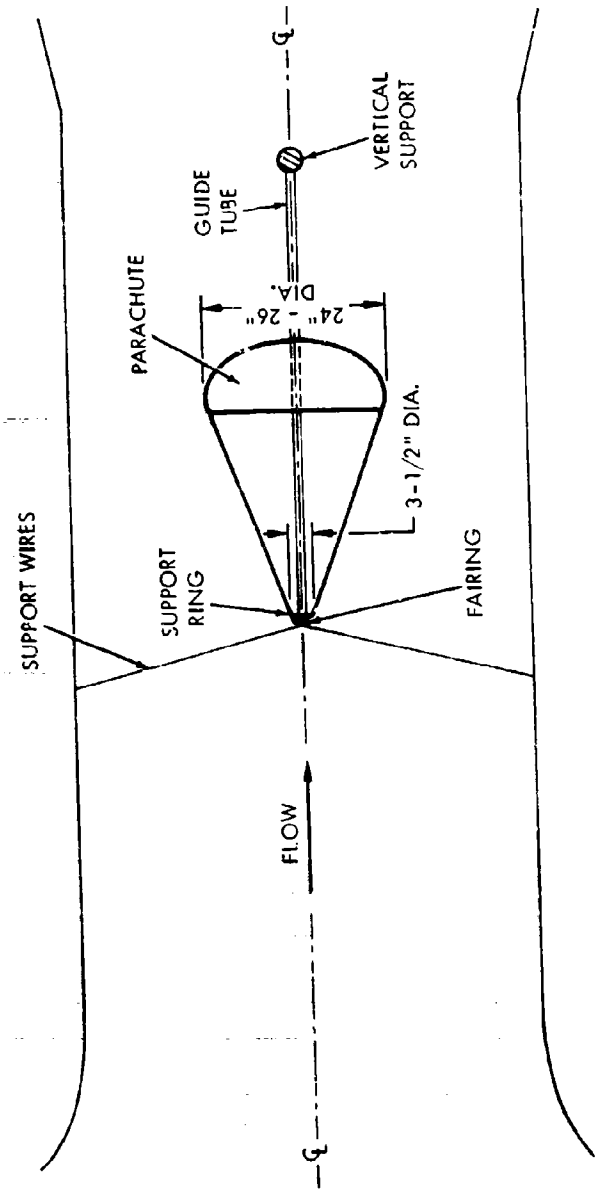


FIG. 3 PLAN VIEW OF WIND TUNNEL SUPPORT AND PHOTOGRAPHIC SYSTEMS

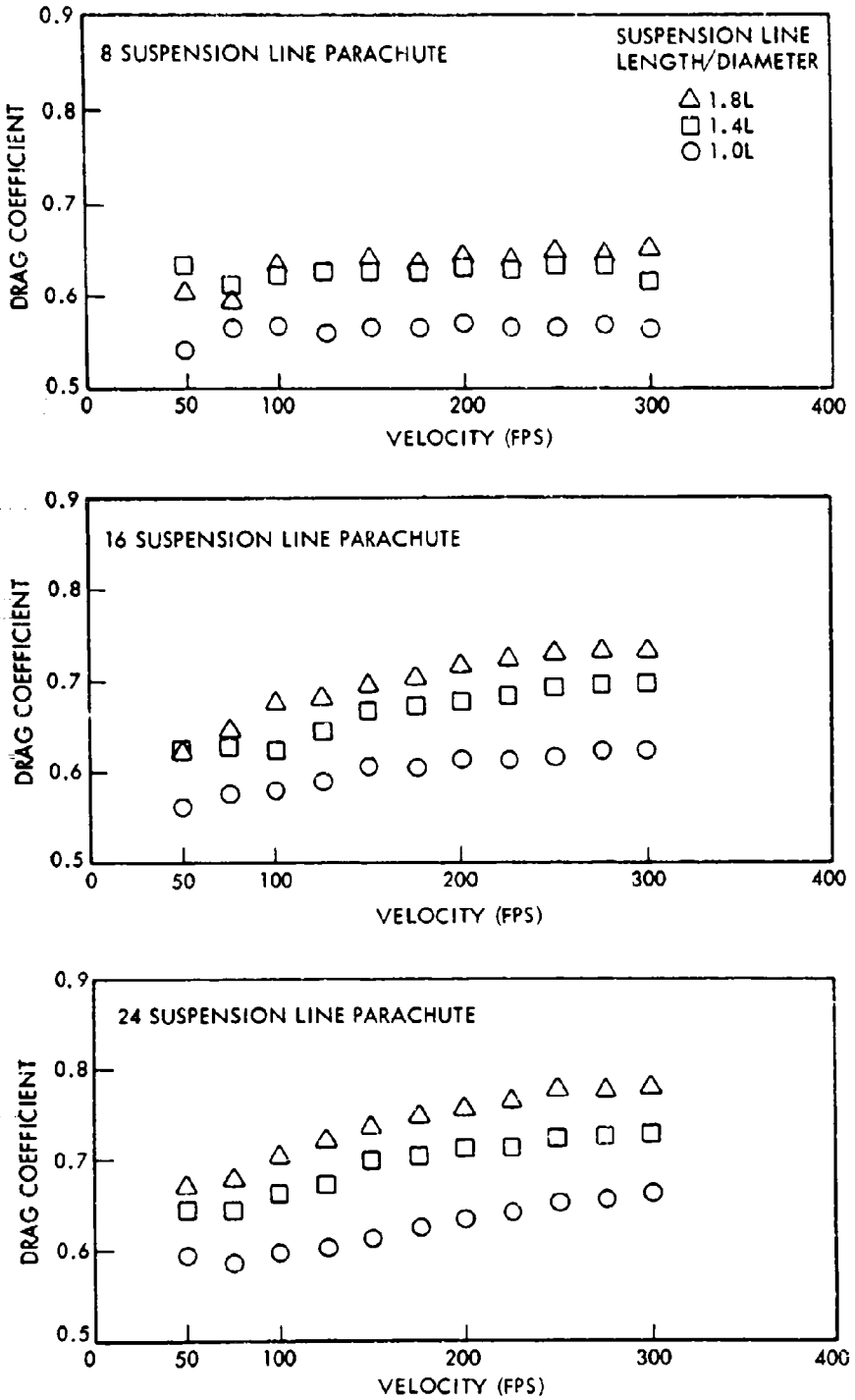


FIG. 4 DRAG COEFFICIENT TEST DATA; PARACHUTE SERIES NO. 2

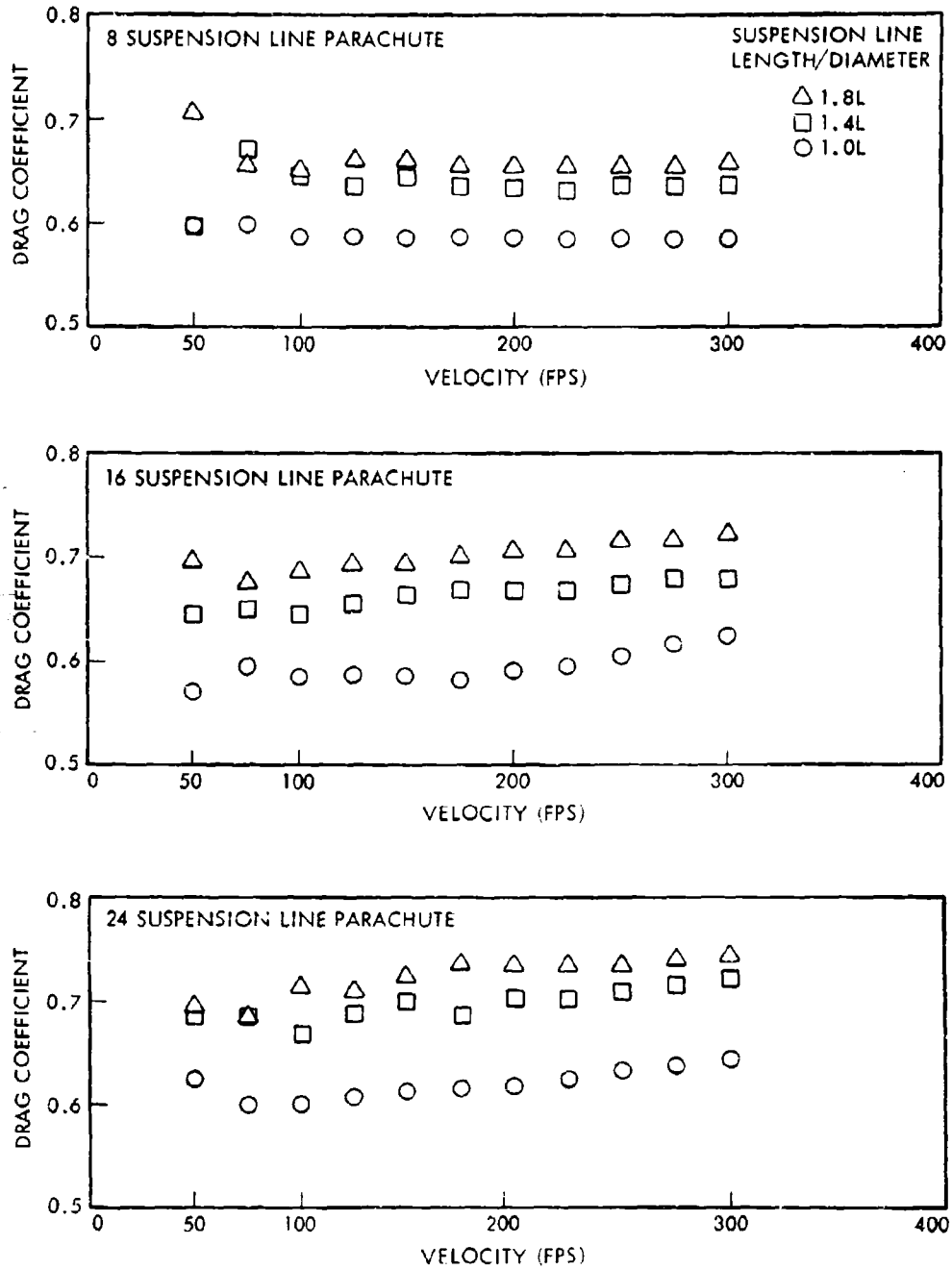
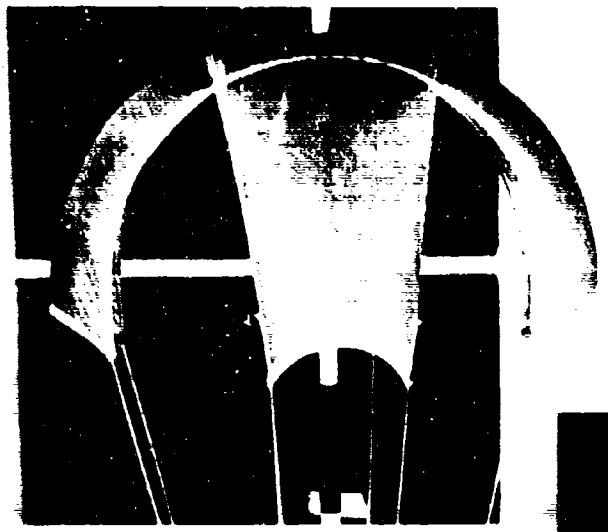


FIG. 5 DRAG COEFFICIENT TEST DATA; PARACHUTE SERIES NO. 3



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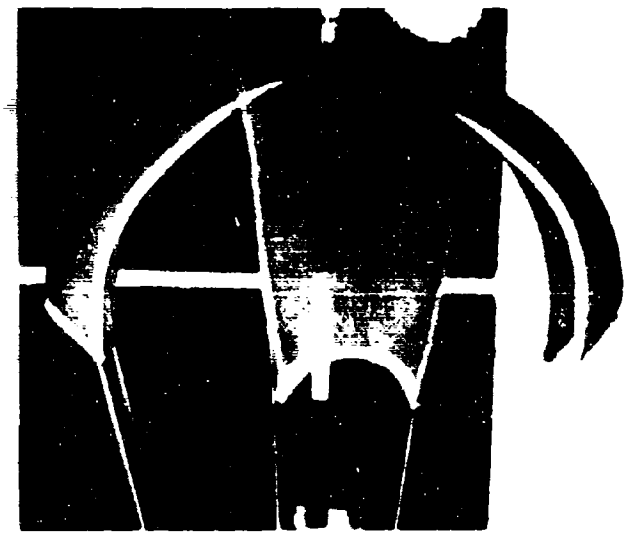

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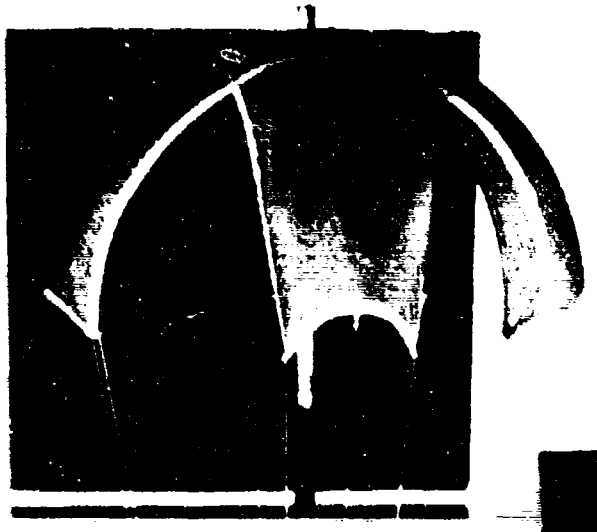
VELOCITY = 200 FPS

FIG. 6 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 8 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L



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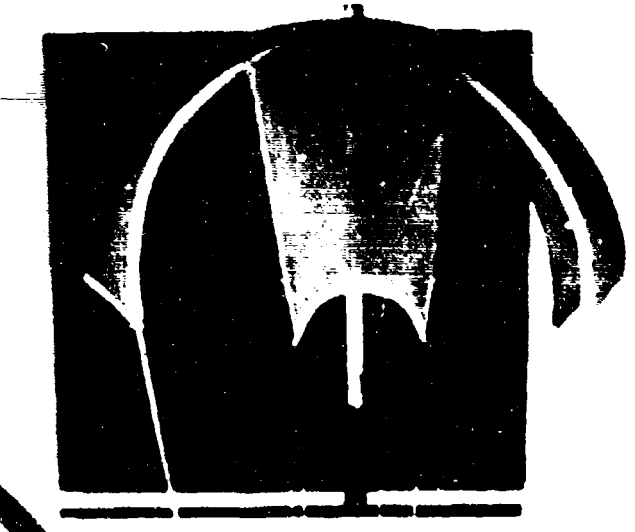

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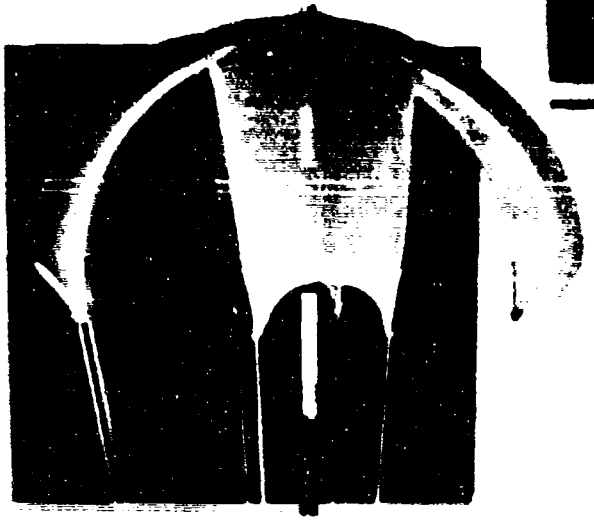

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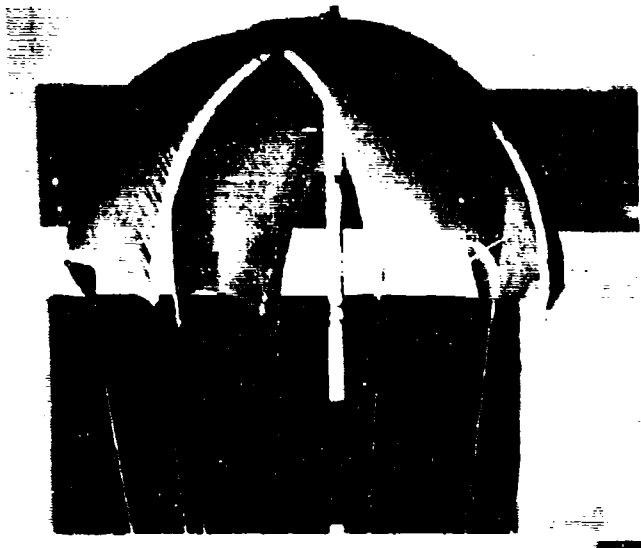
FIG. 7 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 8 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L



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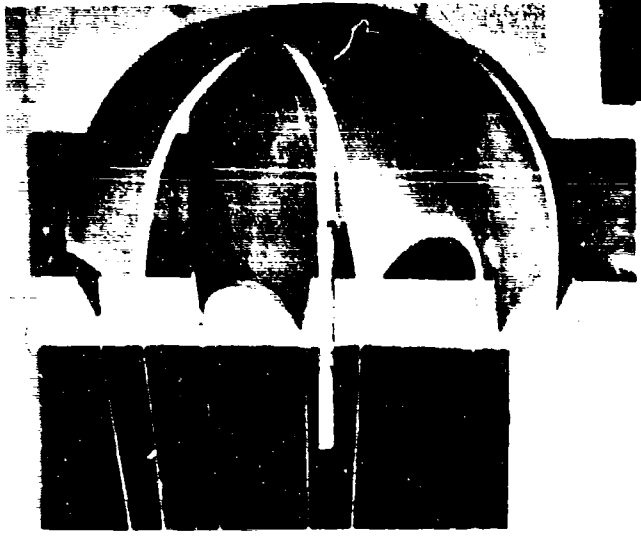

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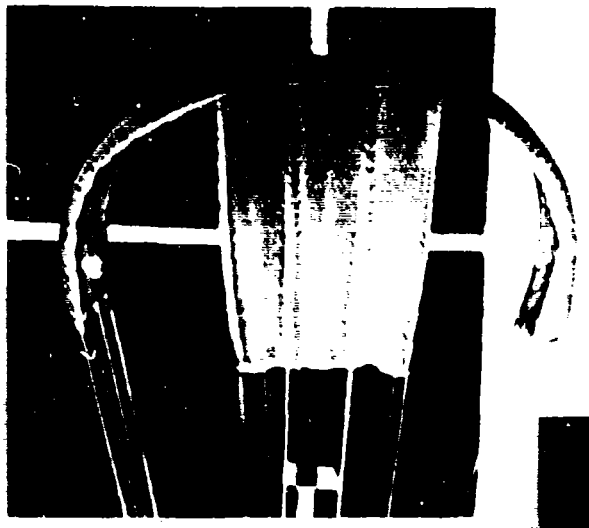
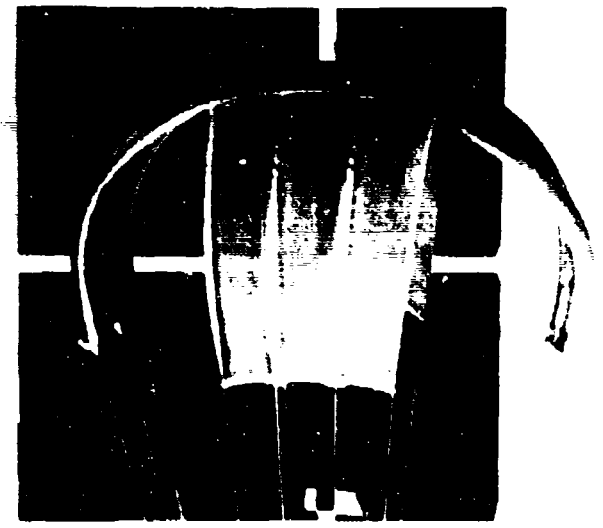
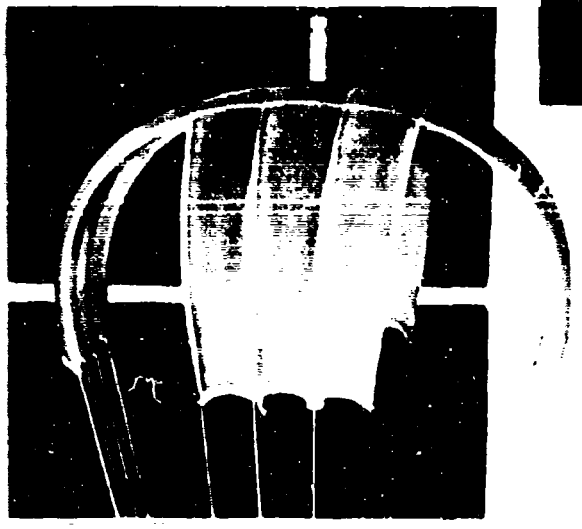
FIG. 8 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 8 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.8 L



VELOCITY = 50 FPS

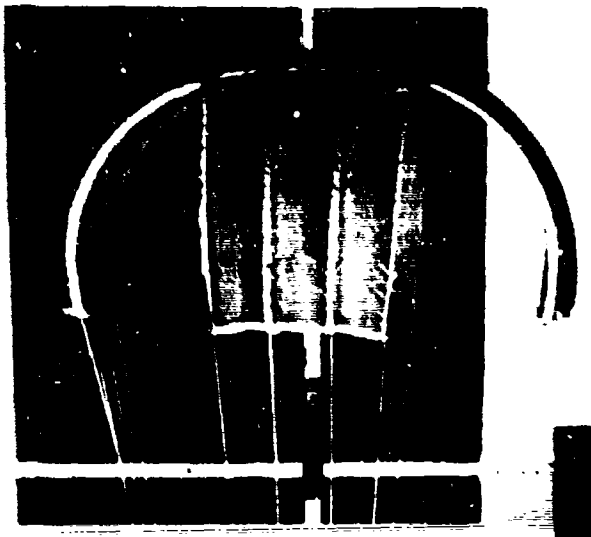


VELOCITY = 100 FPS

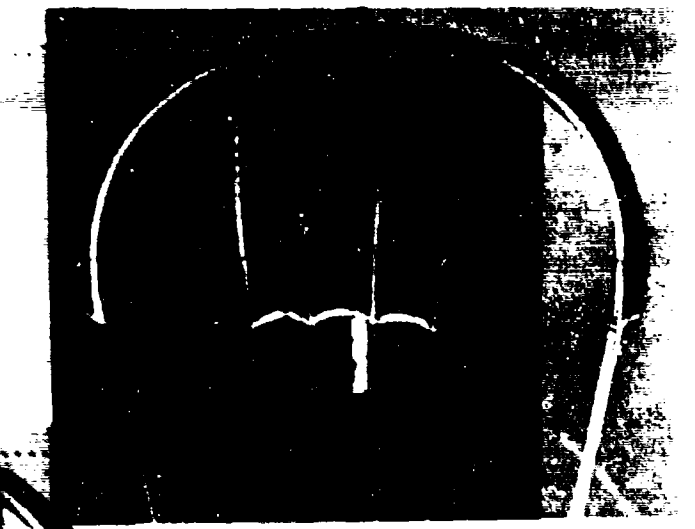


VELOCITY = 200 FPS

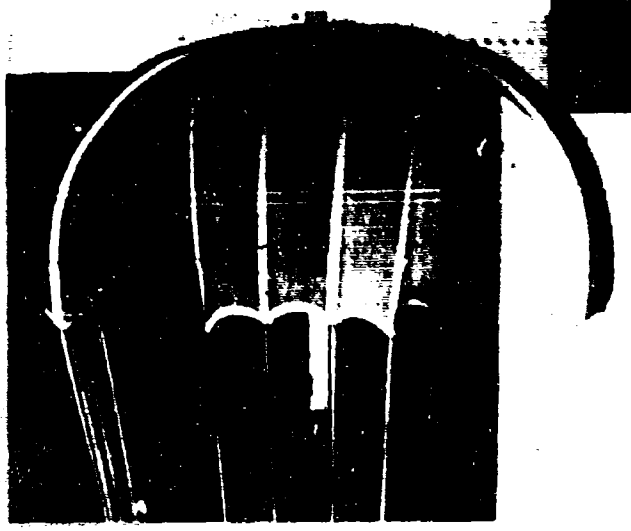
FIG. 9 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L



VELOCITY = 50 FPS



VELOCITY = 100 FPS



VELOCITY = 200 FPS

FIG. 10 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L

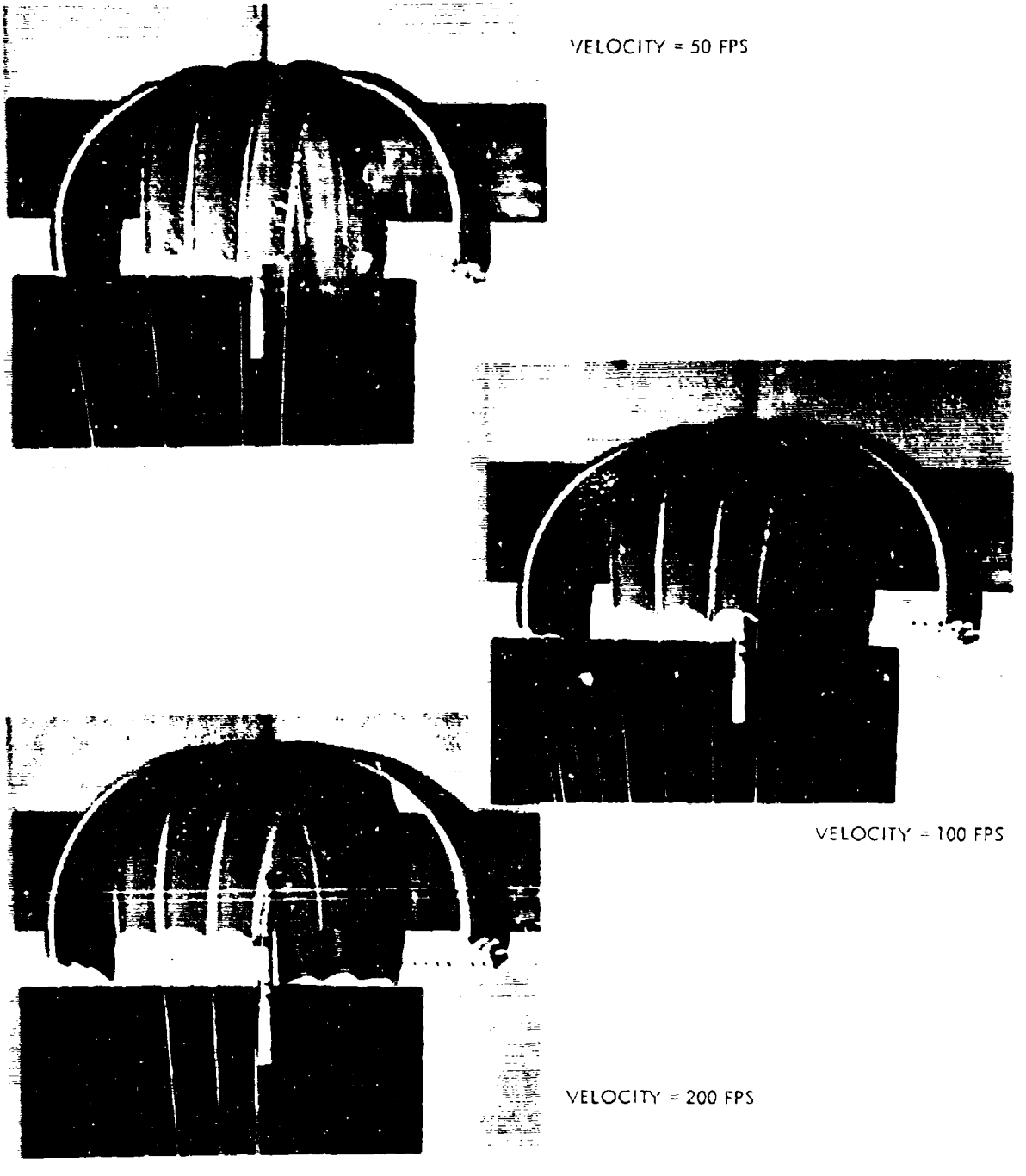
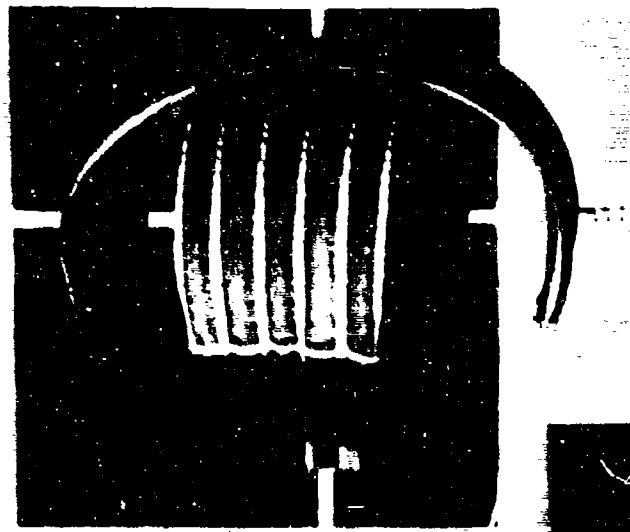
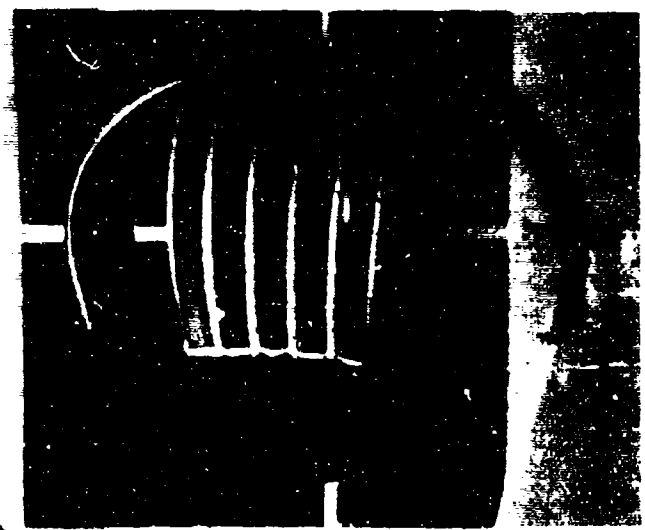


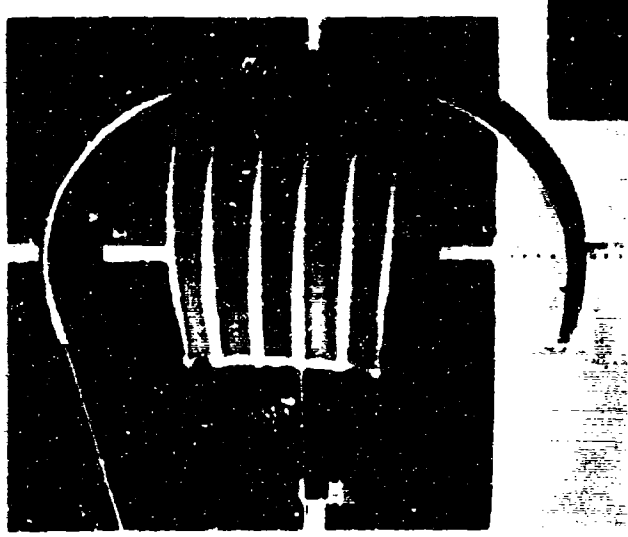
FIG. 11 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 16 SUSPENSION LINE PARACHUTE SUSPENSION LINE LENGTH = 1.8 L



VELOCITY = 50 FPS

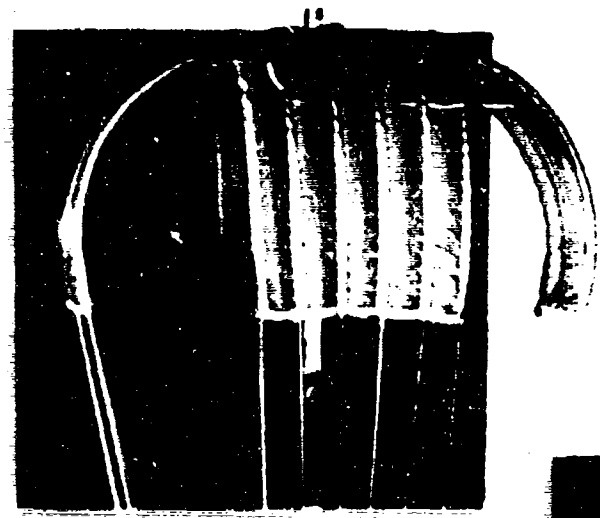


VELOCITY = 100 FPS

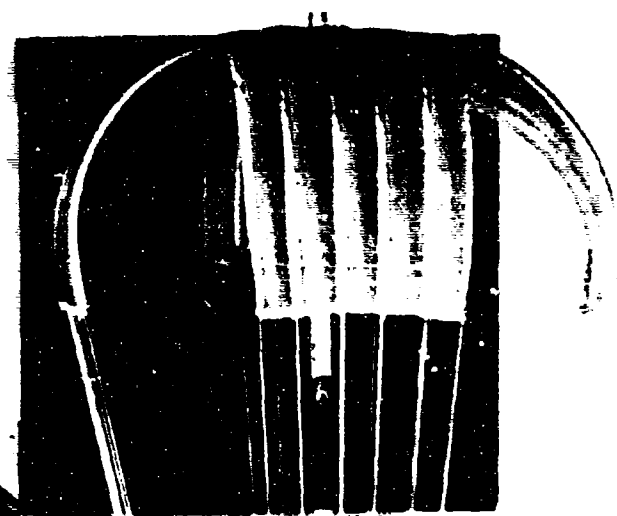


VELOCITY = 200 FPS

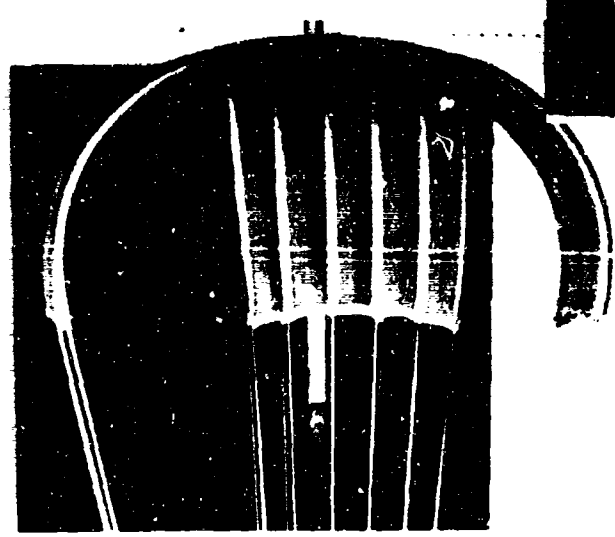
FIG. 12 DRAG COEFFICIENT TEST PARACHUTE SERIES NO. 2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L



VELOCITY = 50 FPS

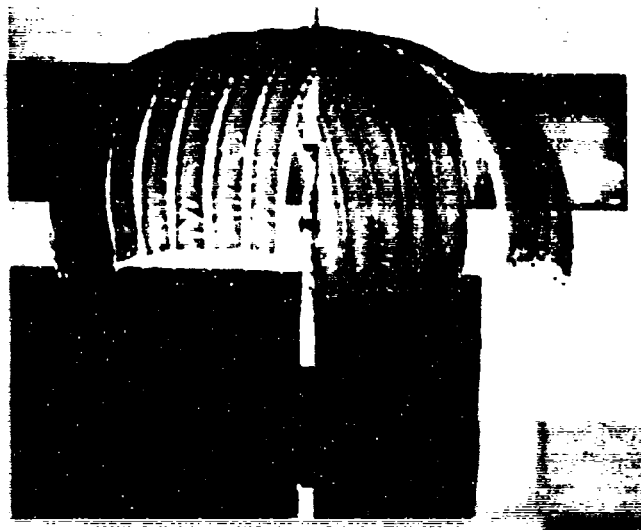


VELOCITY = 100 FPS

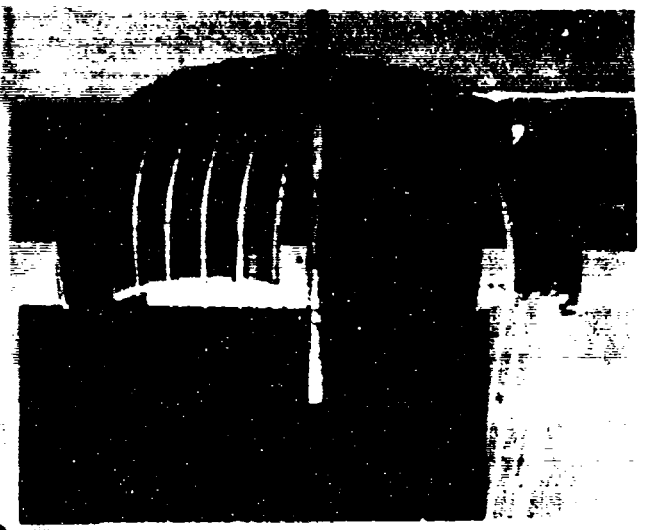


VELOCITY = 200 FPS

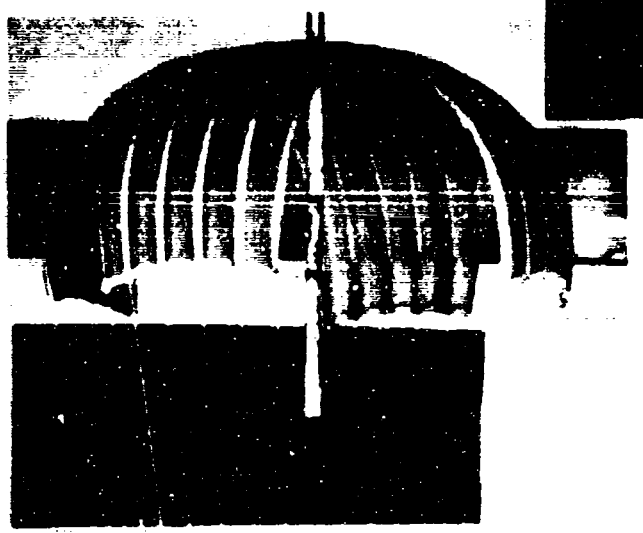
FIG. 13 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L



VELOCITY = 50 FPS

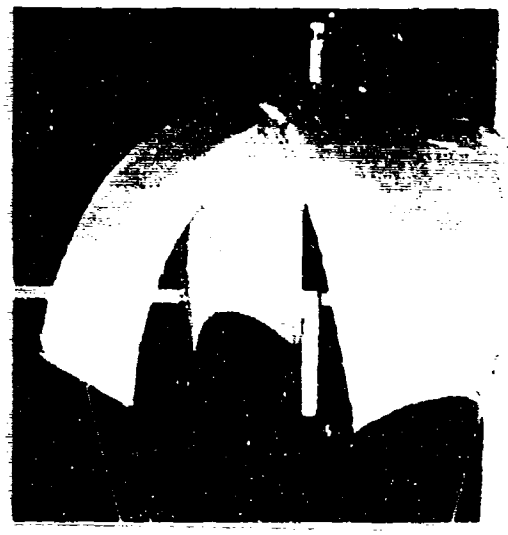


VELOCITY = 100 FPS



VELOCITY = 200 FPS

FIG. 14 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH= 1.8 L

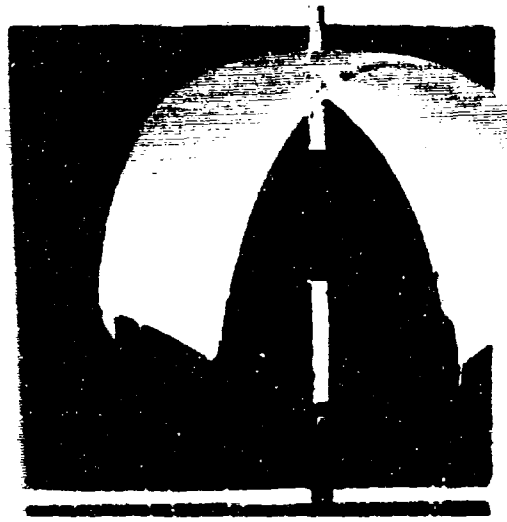


VELOCITY = 50 FPS

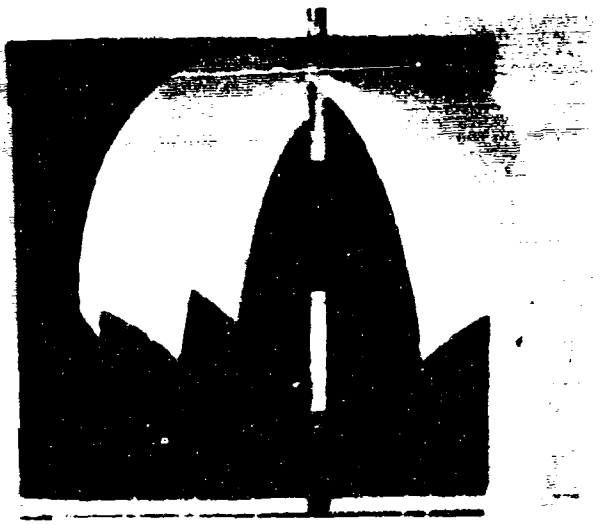
VELOCITY = 100 FPS

VELOCITY = 200 FPS

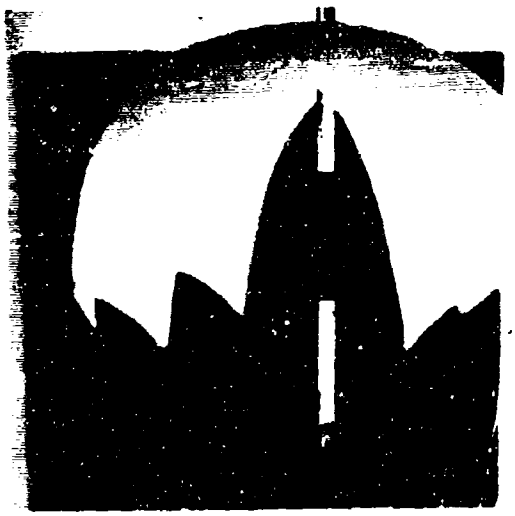
FIG. 15 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 8 SUSPENSION LINE PARACHUTE, SUSPENSION LINE LENGTH = 1.0 L



VELOCITY = 50 FPS



VELOCITY = 100 FPS



VELOCITY = 200 FPS

FIG. 16 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 8 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L

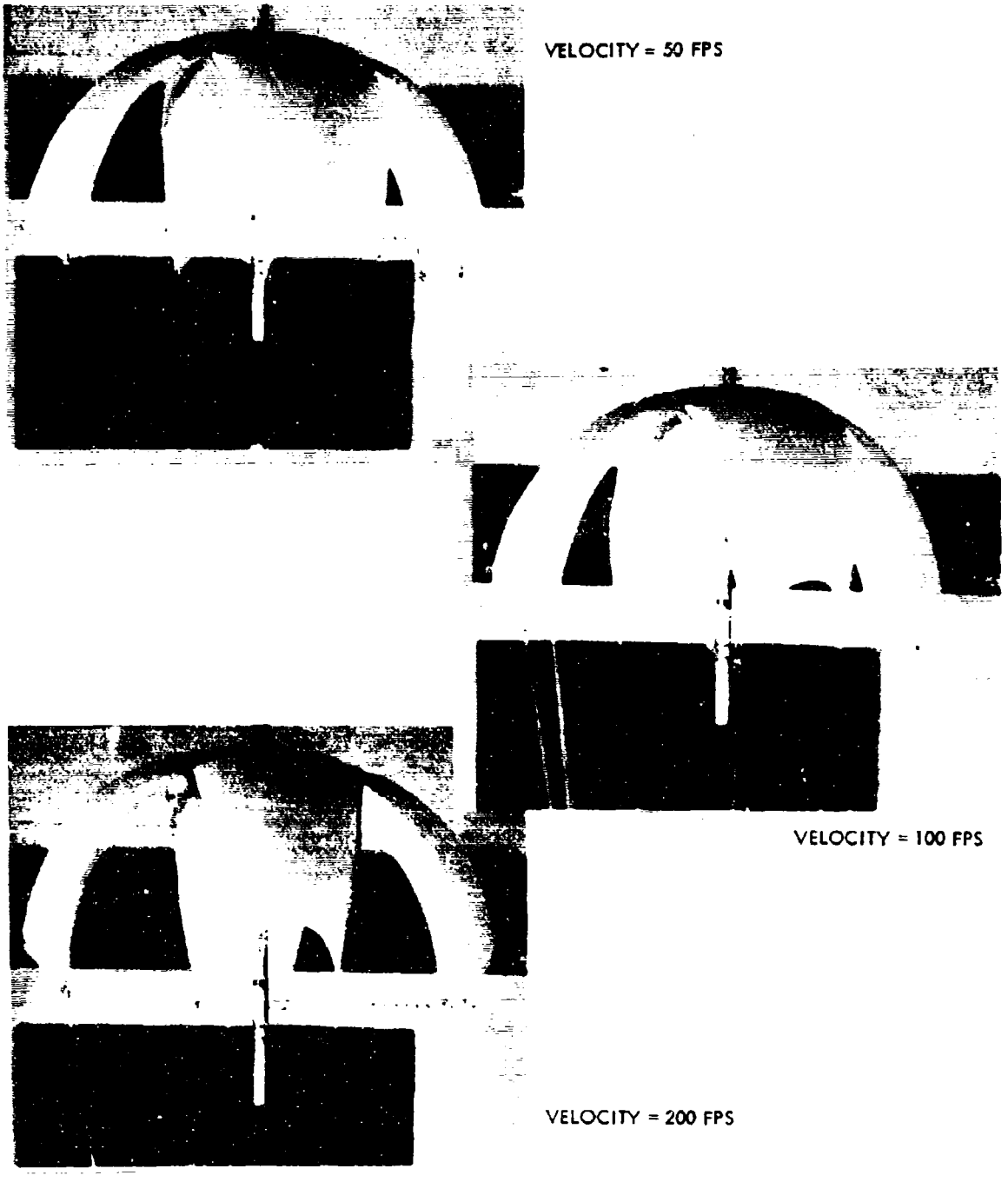


FIG. 17 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 8 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.8 L

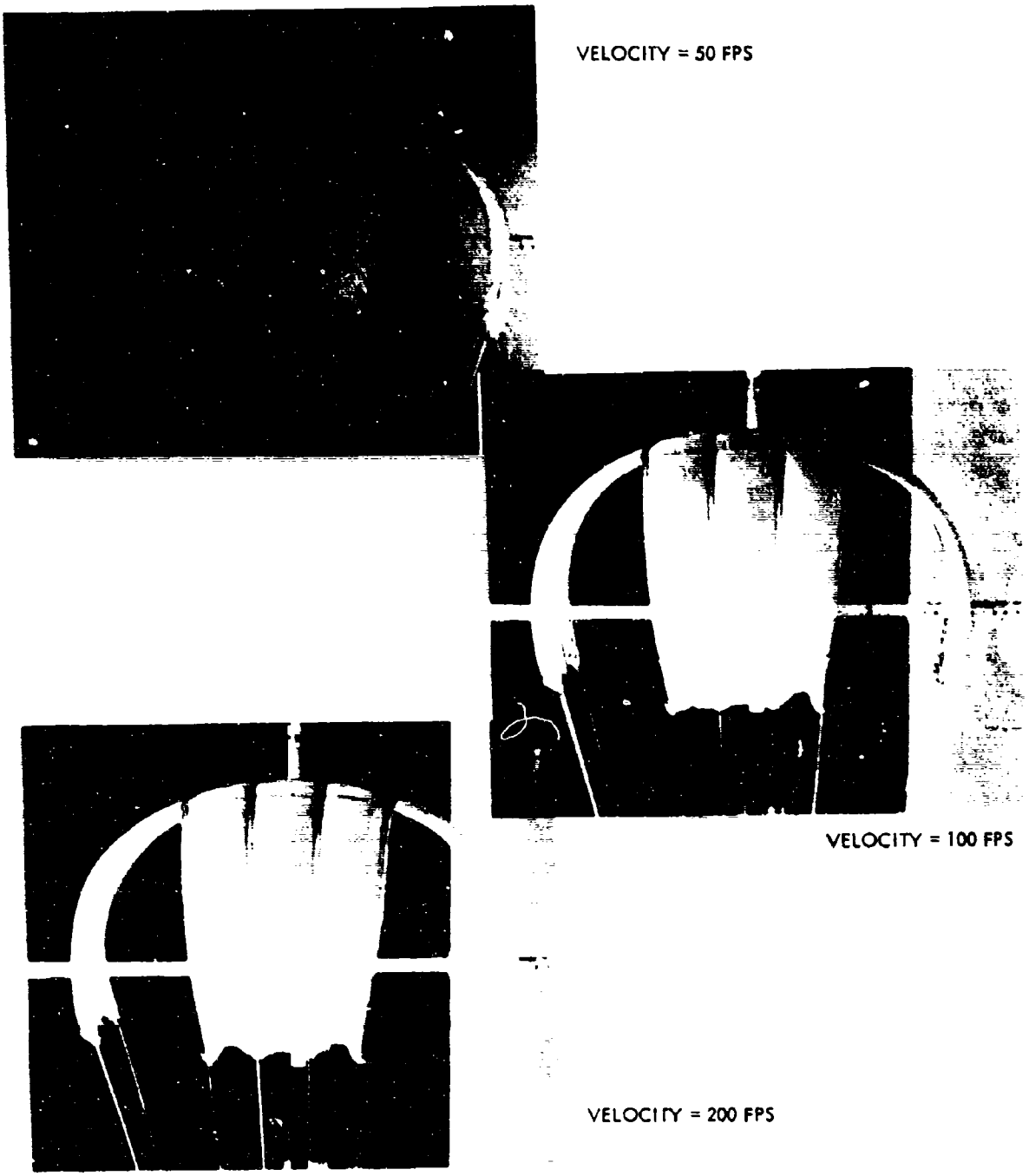
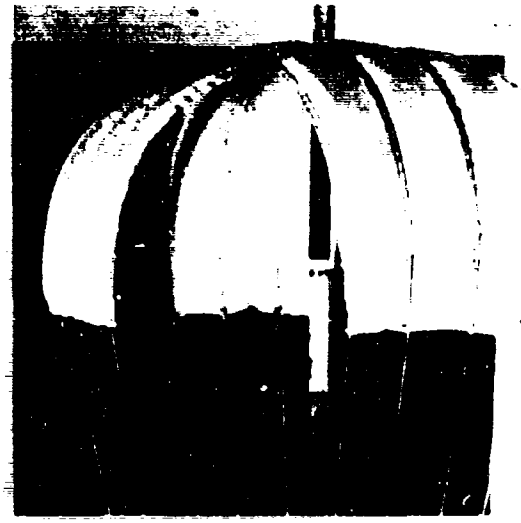
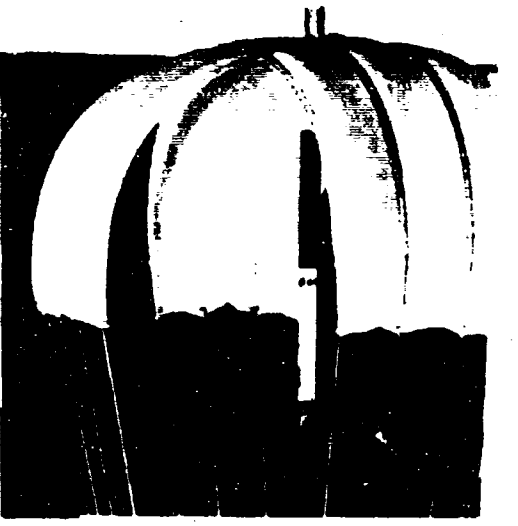


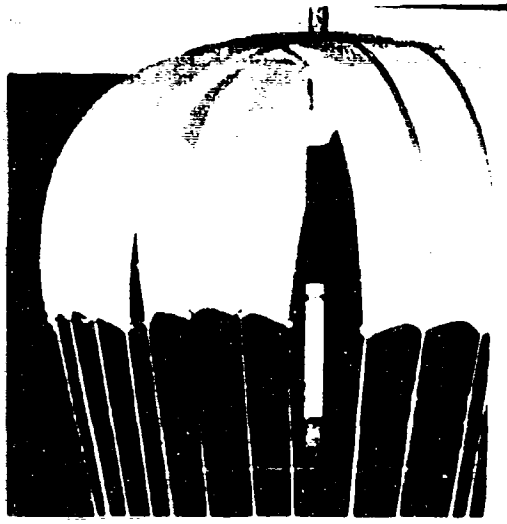
FIG. 18 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L



VELOCITY = 50 FPS

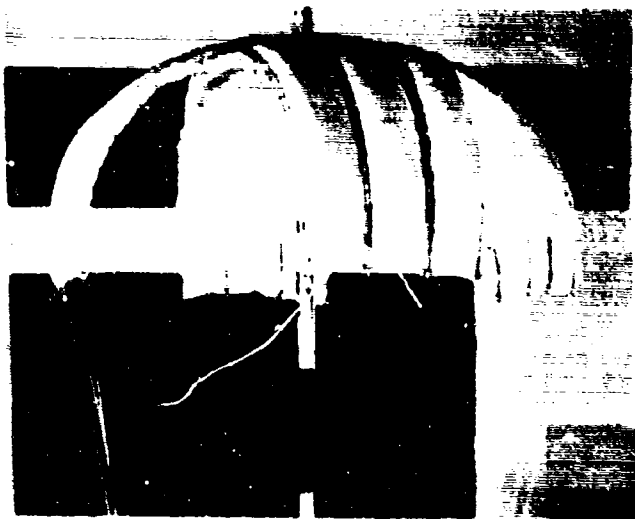


VELOCITY = 100 FPS



VELOCITY = 200 FPS

FIG. 19 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L



VELOCITY = 50 FPS

VELOCITY = 100 FPS

VELOCITY = 200 FPS

FIG. 20 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.8 L

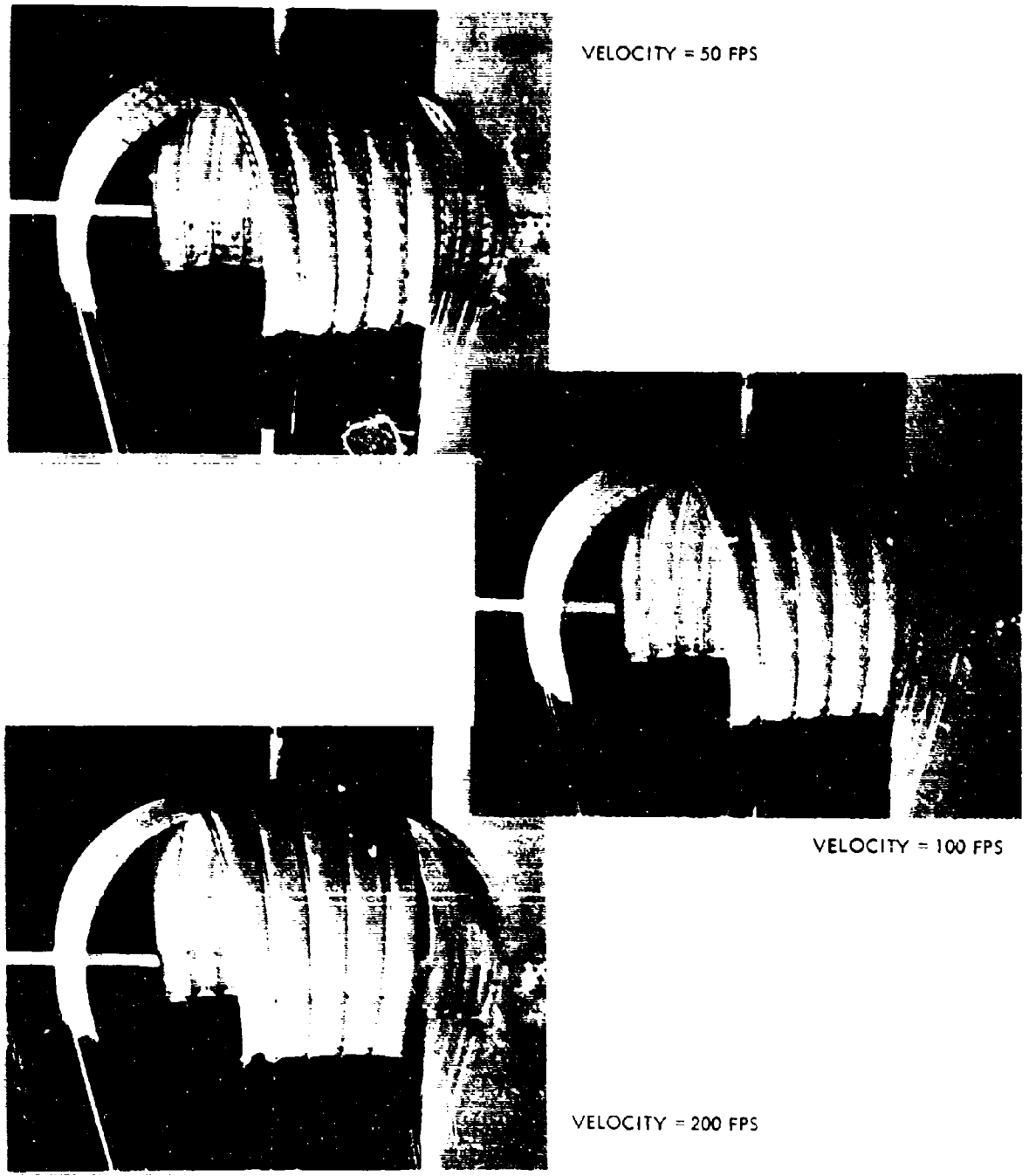
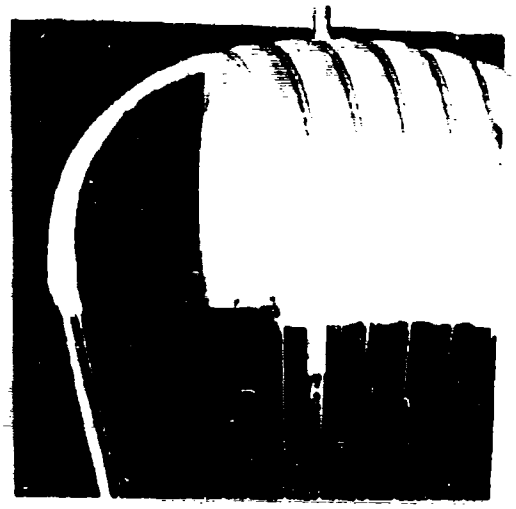
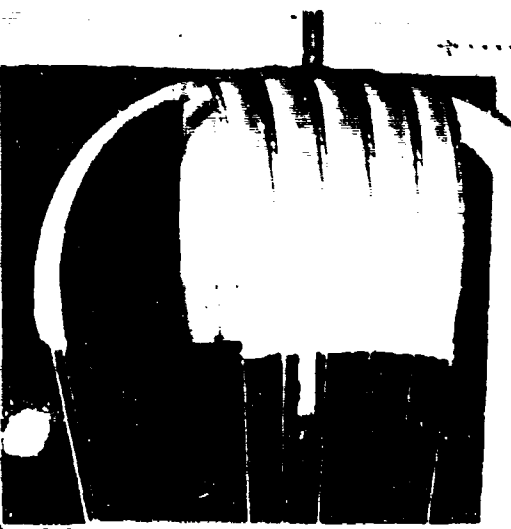


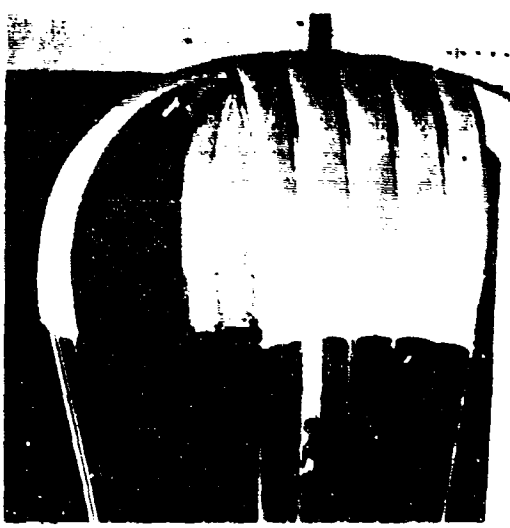
FIG. 21 DRAG COEFFICIENT TEST, PARACHUTE SERIES NO. 3; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L



VELOCITY = 50 FPS



VELOCITY = 100 FPS



VELOCITY = 200 FPS

FIG. 22 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L

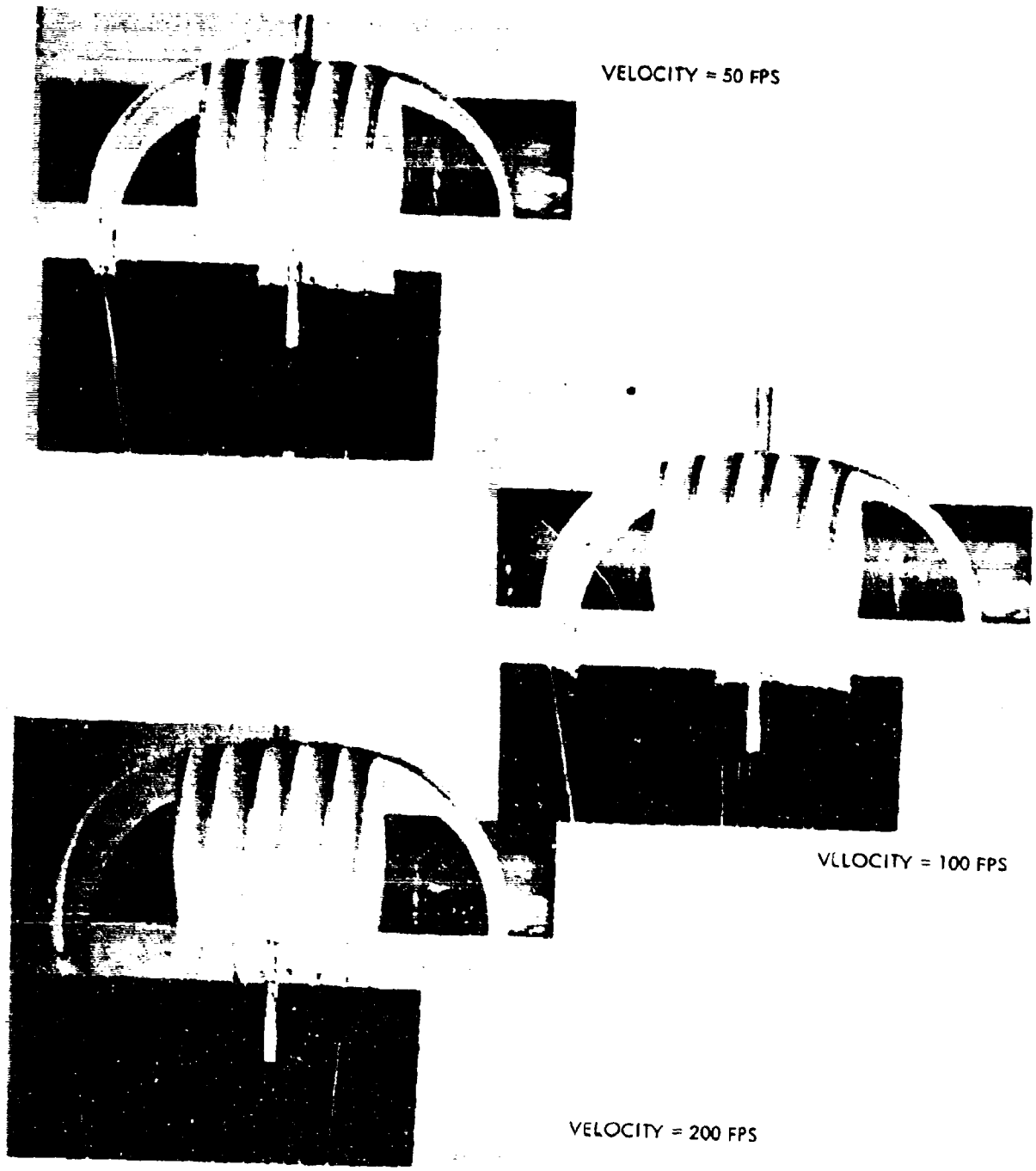


FIG. 23 DRAG COEFFICIENT TEST; PARACHUTE SERIES NO. 3; 24 SUSPENSION LINE PARACHUTE: SUSPENSION LINE LENGTH = 1.8 L

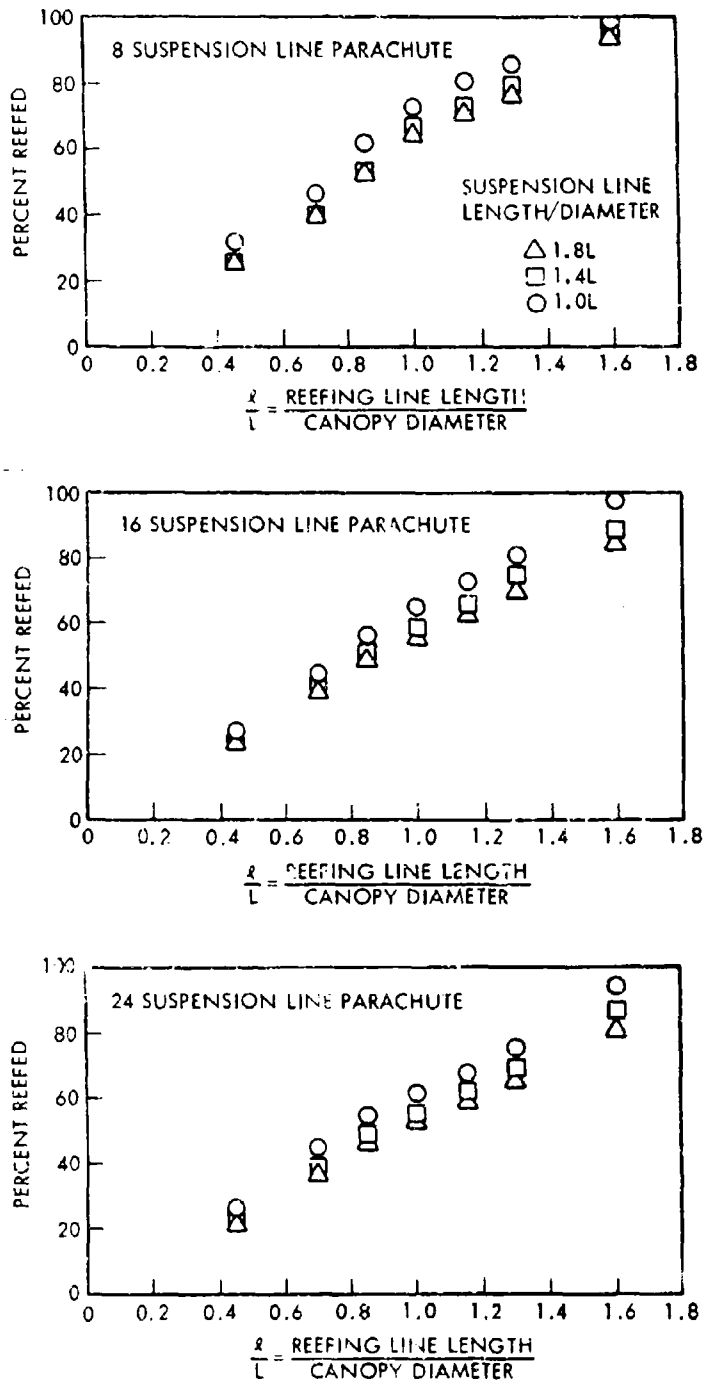


FIG. 24 REEFED CANOPY TEST DATA; PARACHUTE SERIES NO. 2
TEST VELOCITY = 275 FPS

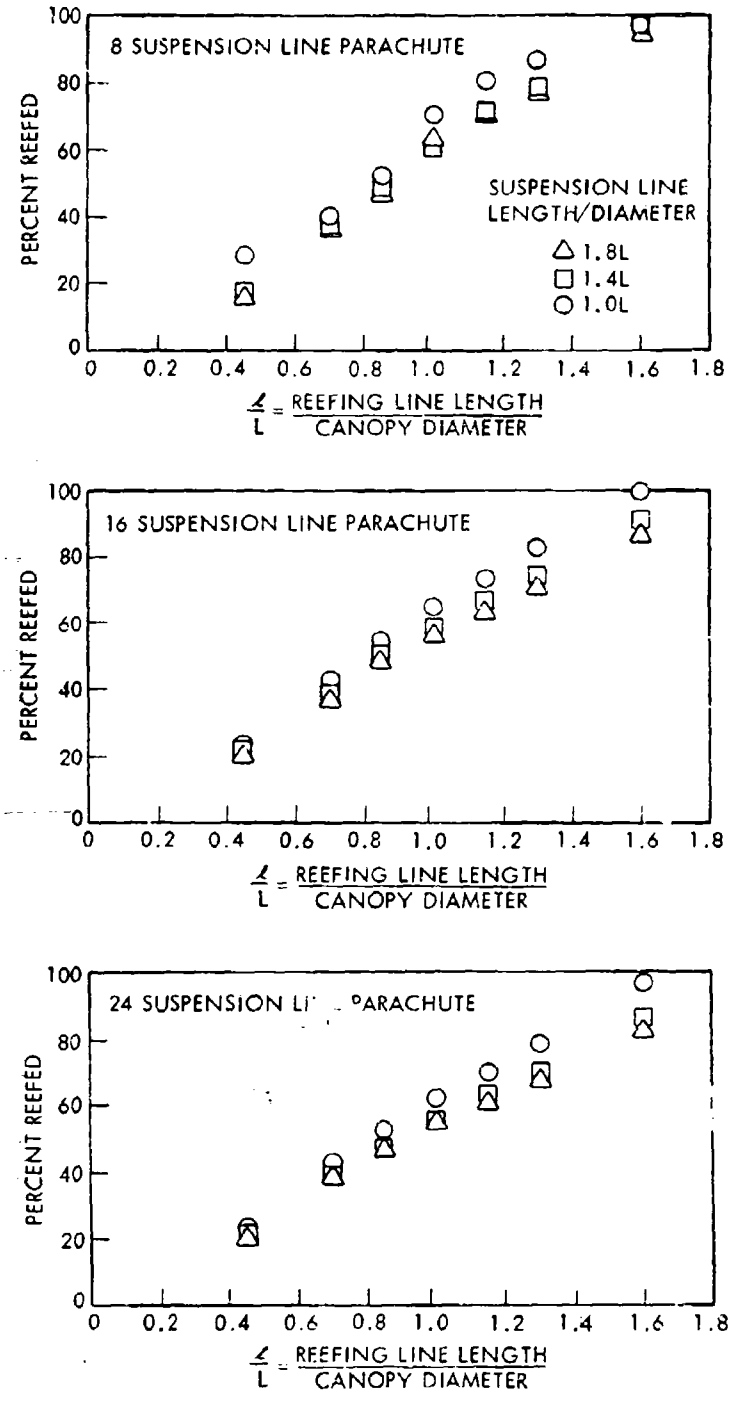


FIG. 25 REEFED CANOPY TEST DATA; PARACHUTE SERIES NO. 3
TEST VELOCITY = 275 FPS

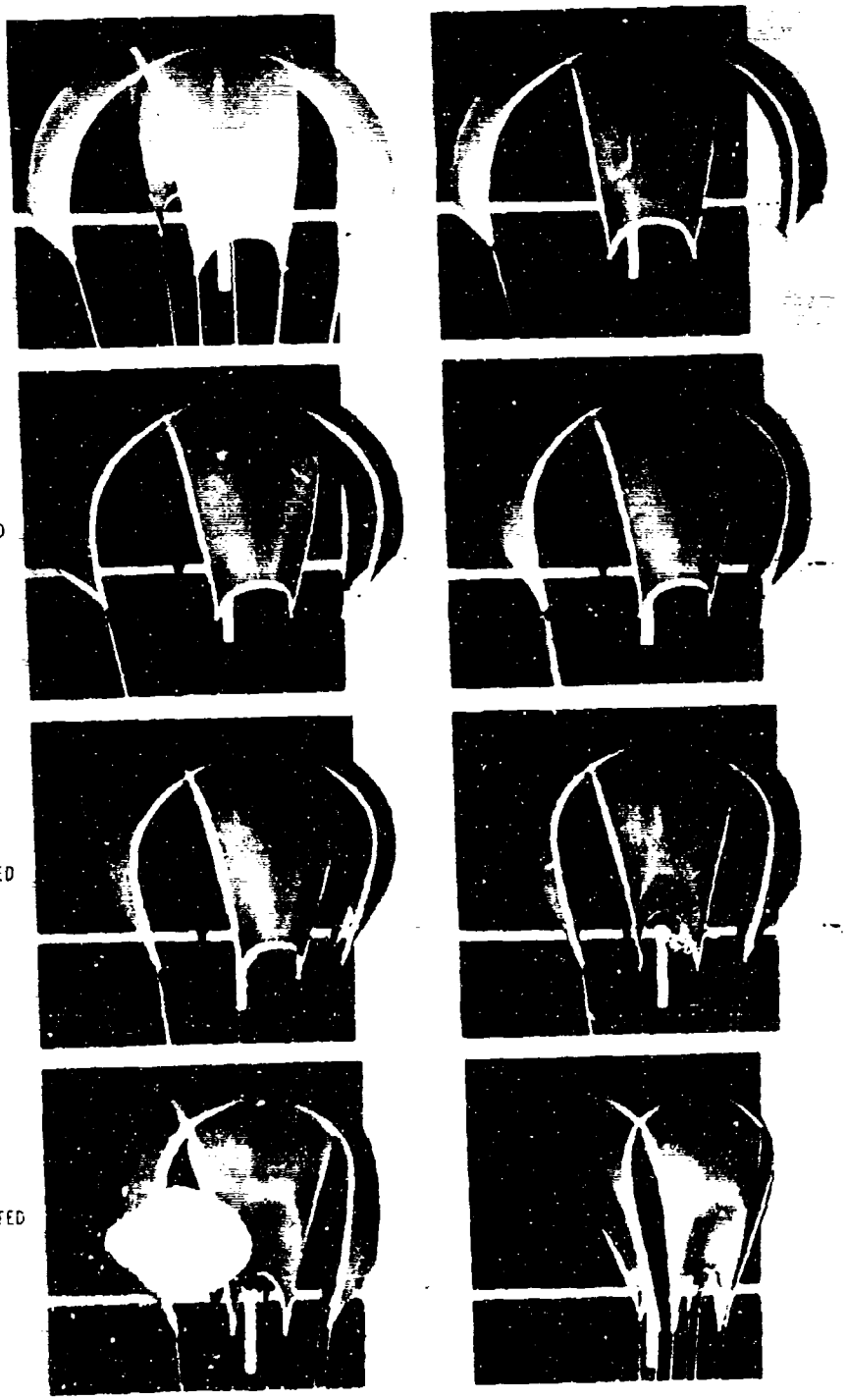


FIG. 13 REEFED SNORT TEST PARACHUTE SERIES NO. 2 × SUSPENSION LINE
PARACHUTE SUSPENSION LINE LENGTH = 181' TEST VELOCITY = 275 FPS

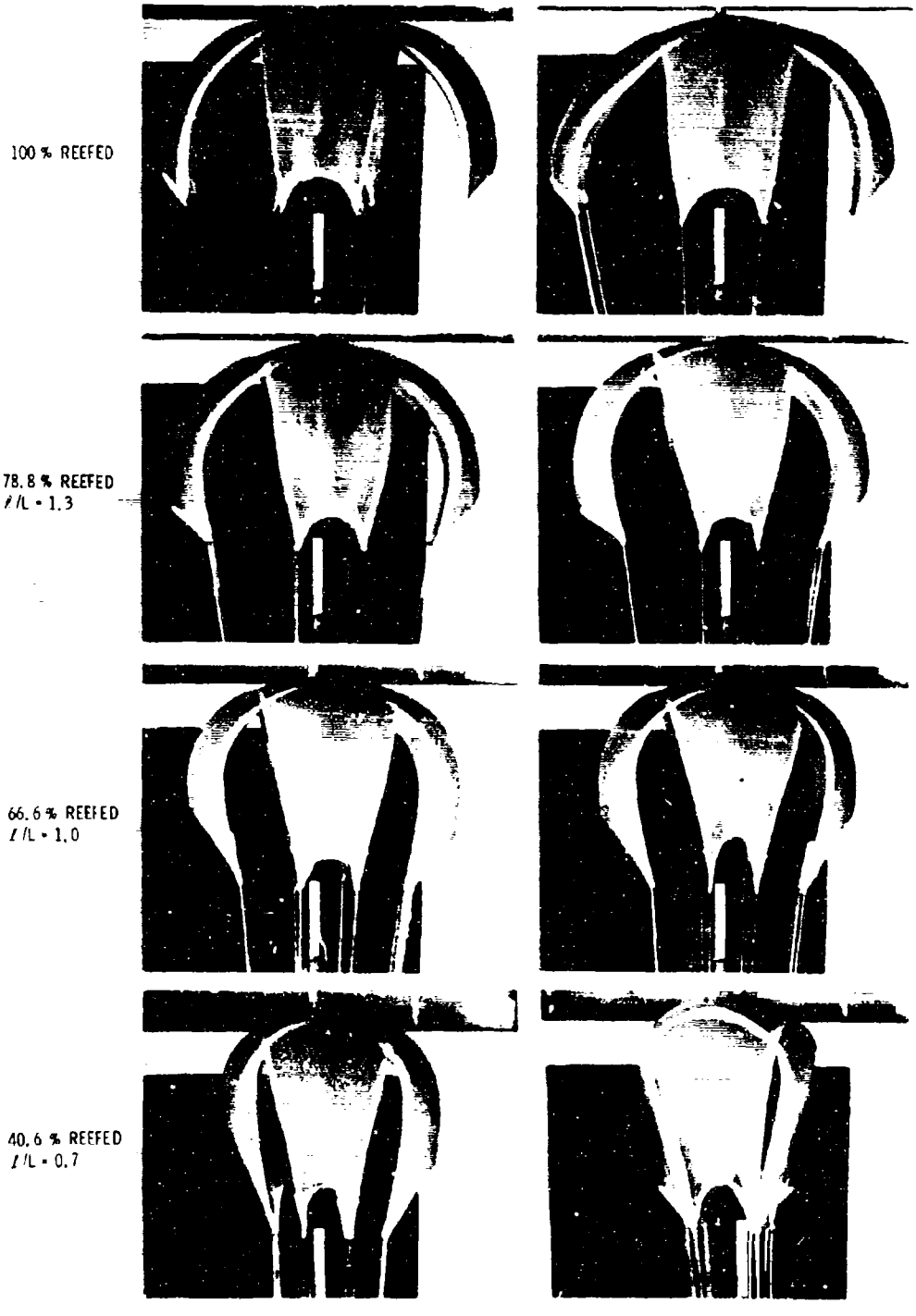


FIG. 27 REEFED CANOPY TEST: PARACHUTE SERIES NO. 2-5 SUSPENSION LINE
PARACHUTE-SUSPENSION LINE LENGTH [illegible] TEST VELOCITY = 275 FPS

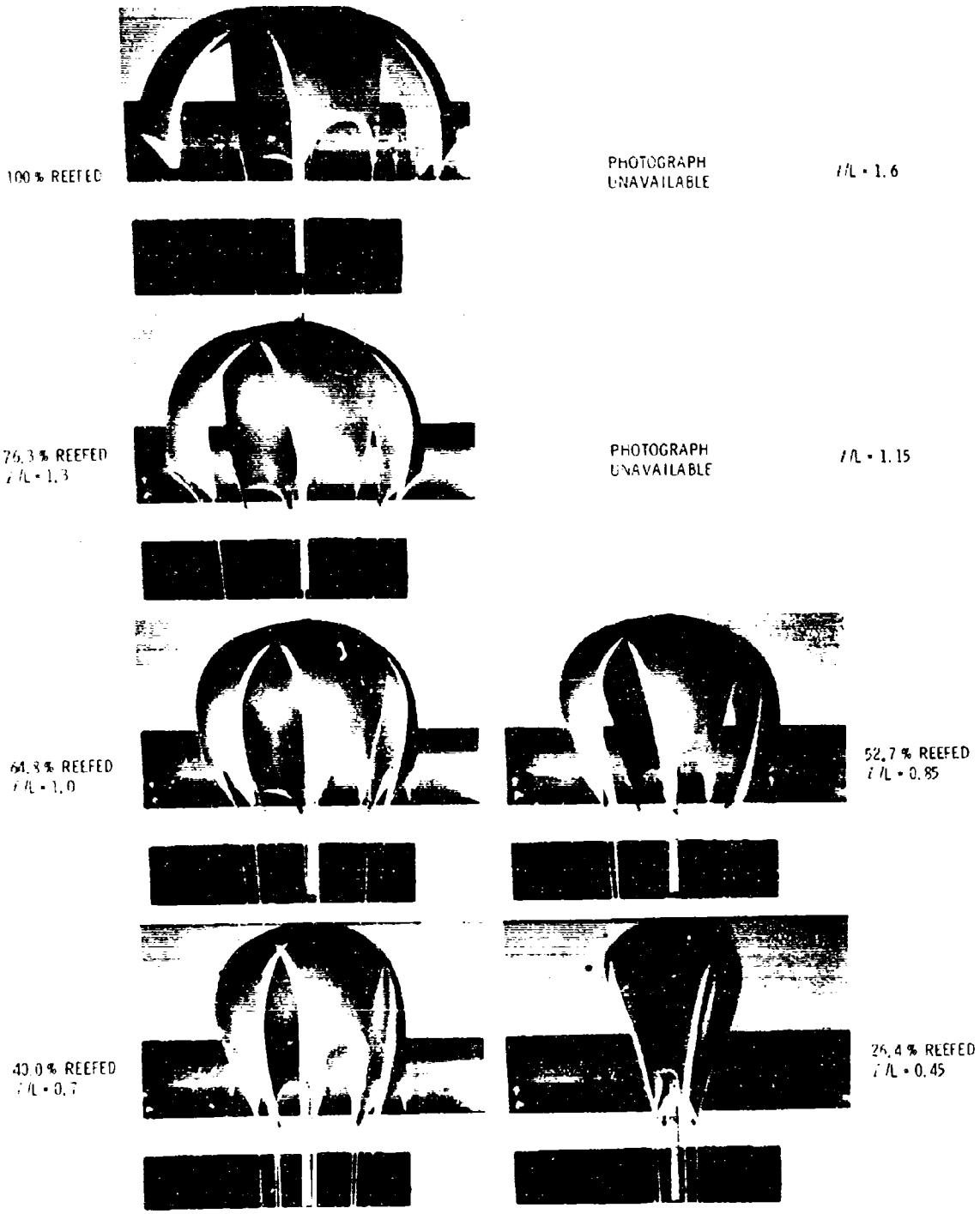


FIG. 2- PHOTOGRAPHS OF TEST PORTION OF SERIES [illegible] SUSPENSION LINE
PARACHUTE SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 275 FPS

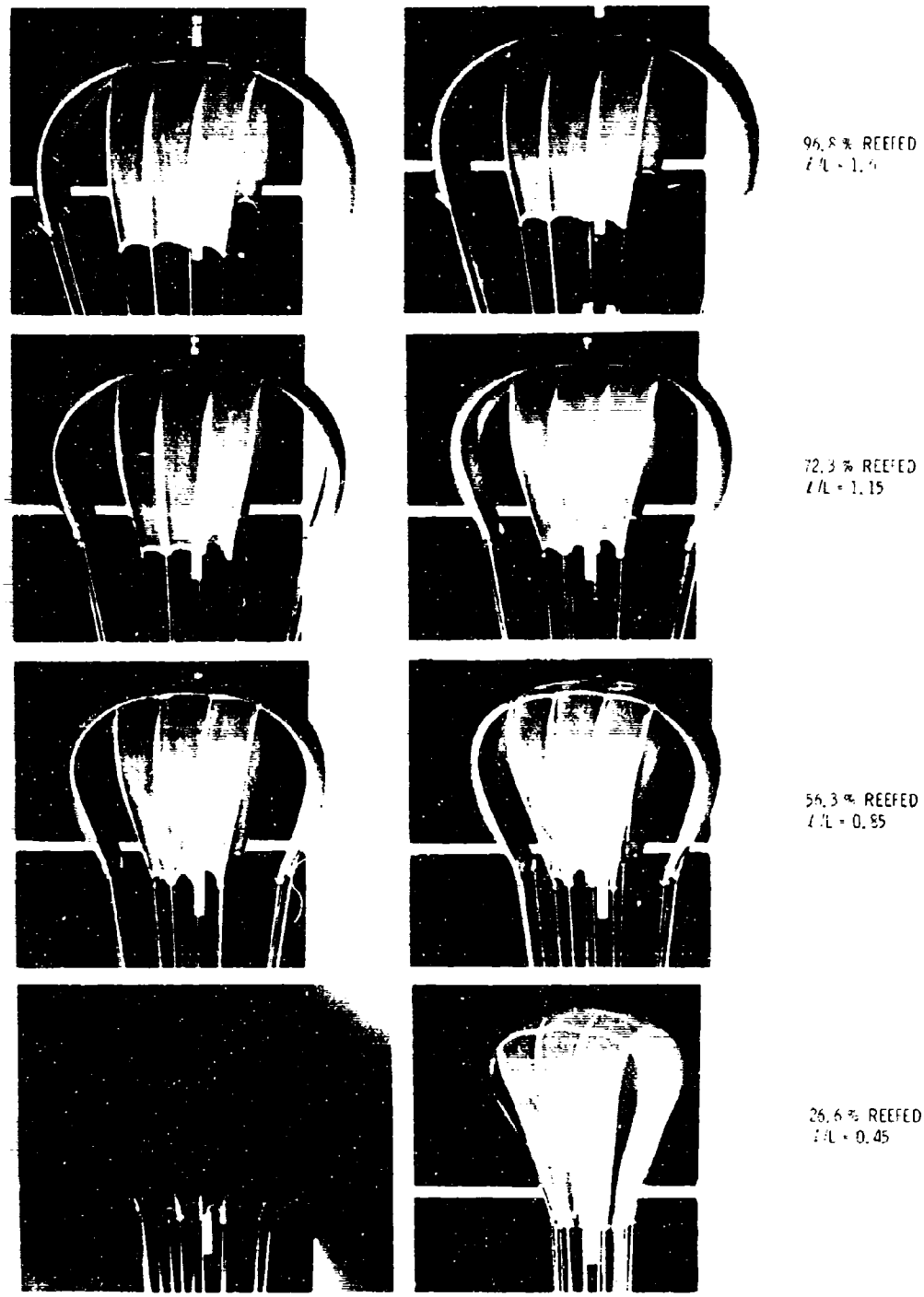


FIG. 29 REEFED CANOPY TEST PARACHUTE SHAPES IN SPECIFIED PARACHUTE SUSPENSION LINE LENGTHS

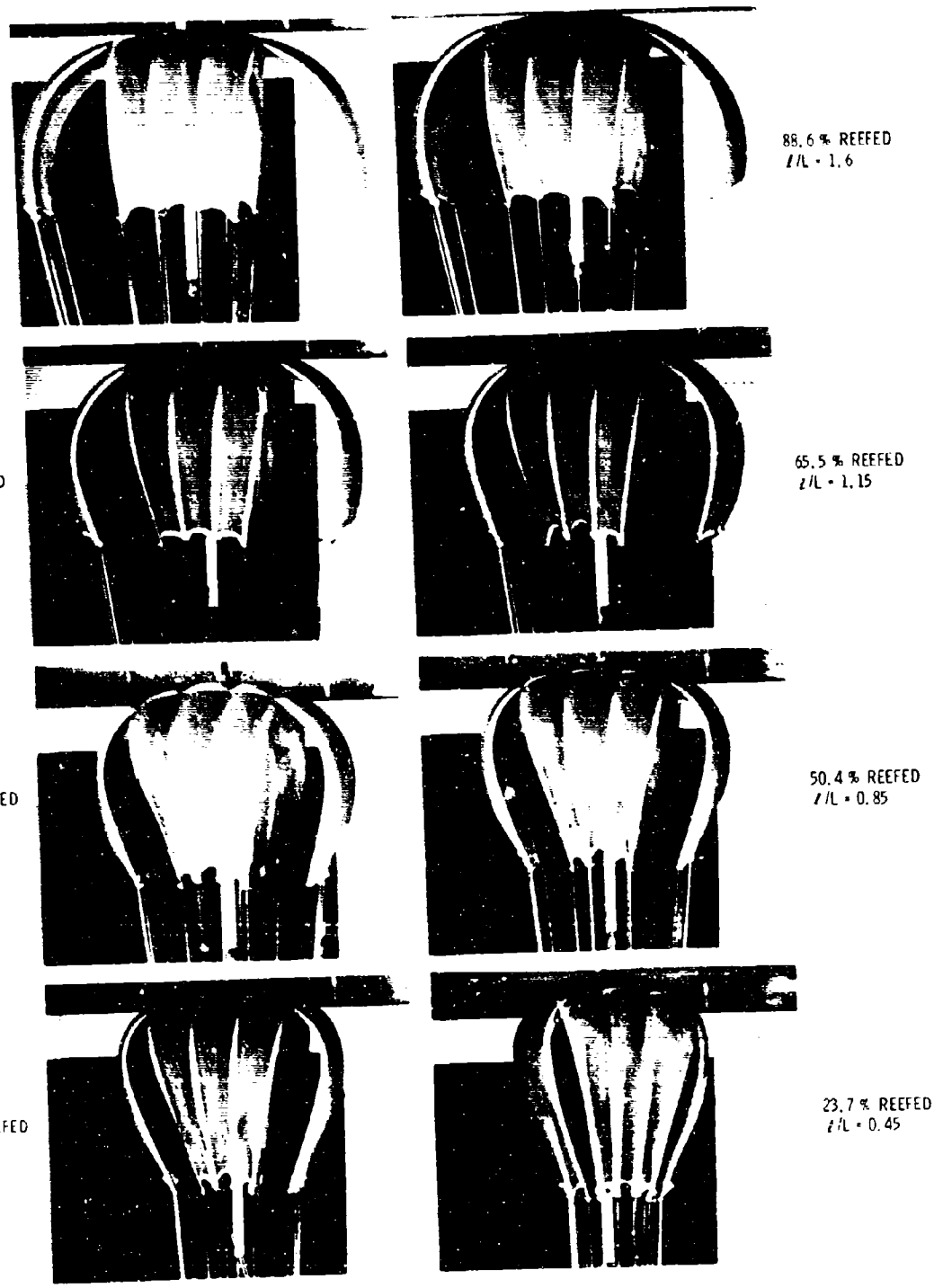


FIG. 39 REEFED CANOPY TEST PARACHUTE SERIES [illegible] SPECIFICATION, 1.1 PARACHUTE SPECIFICATION LINE LENGTH [illegible] TEST VELOCITY = 275 FPS

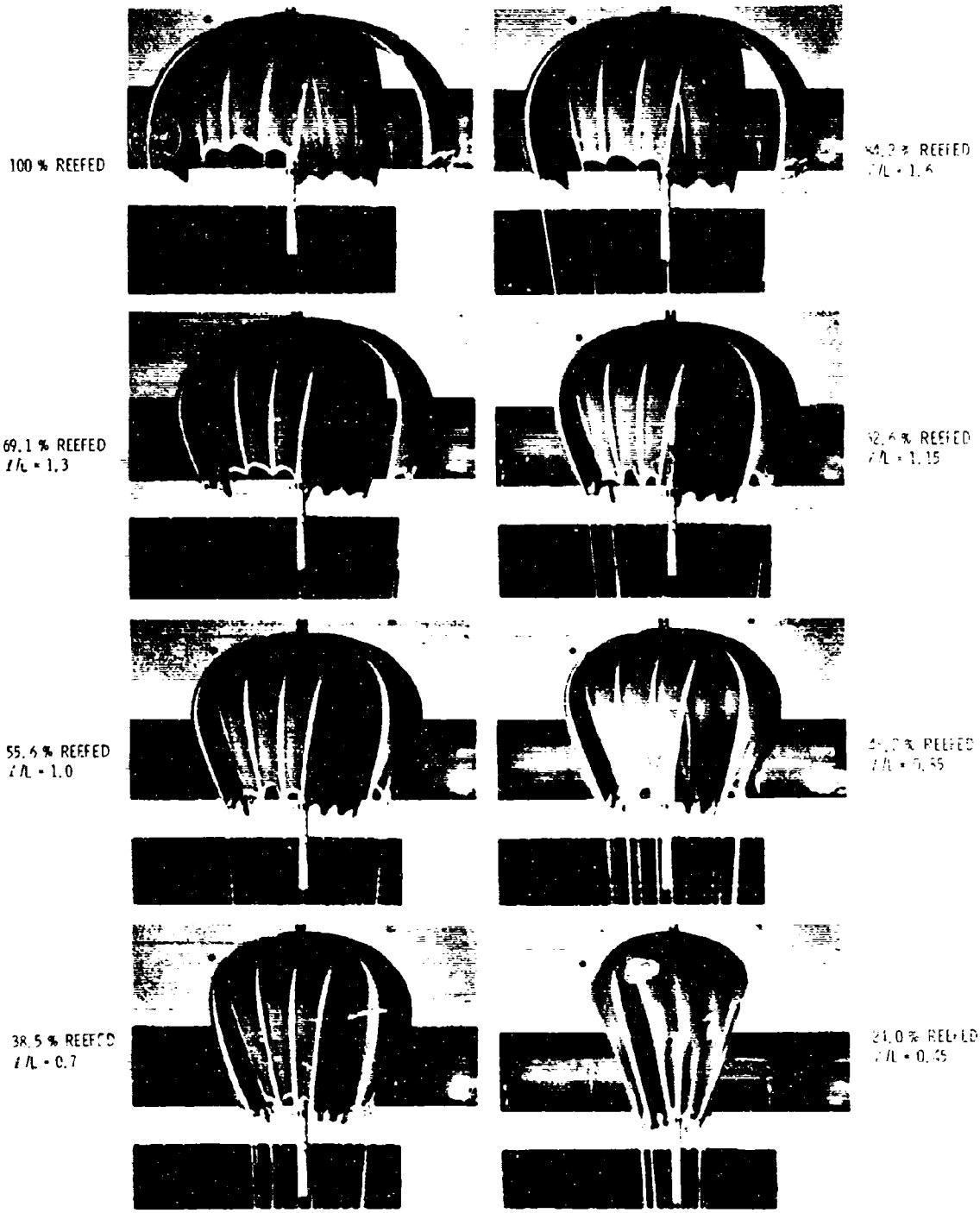
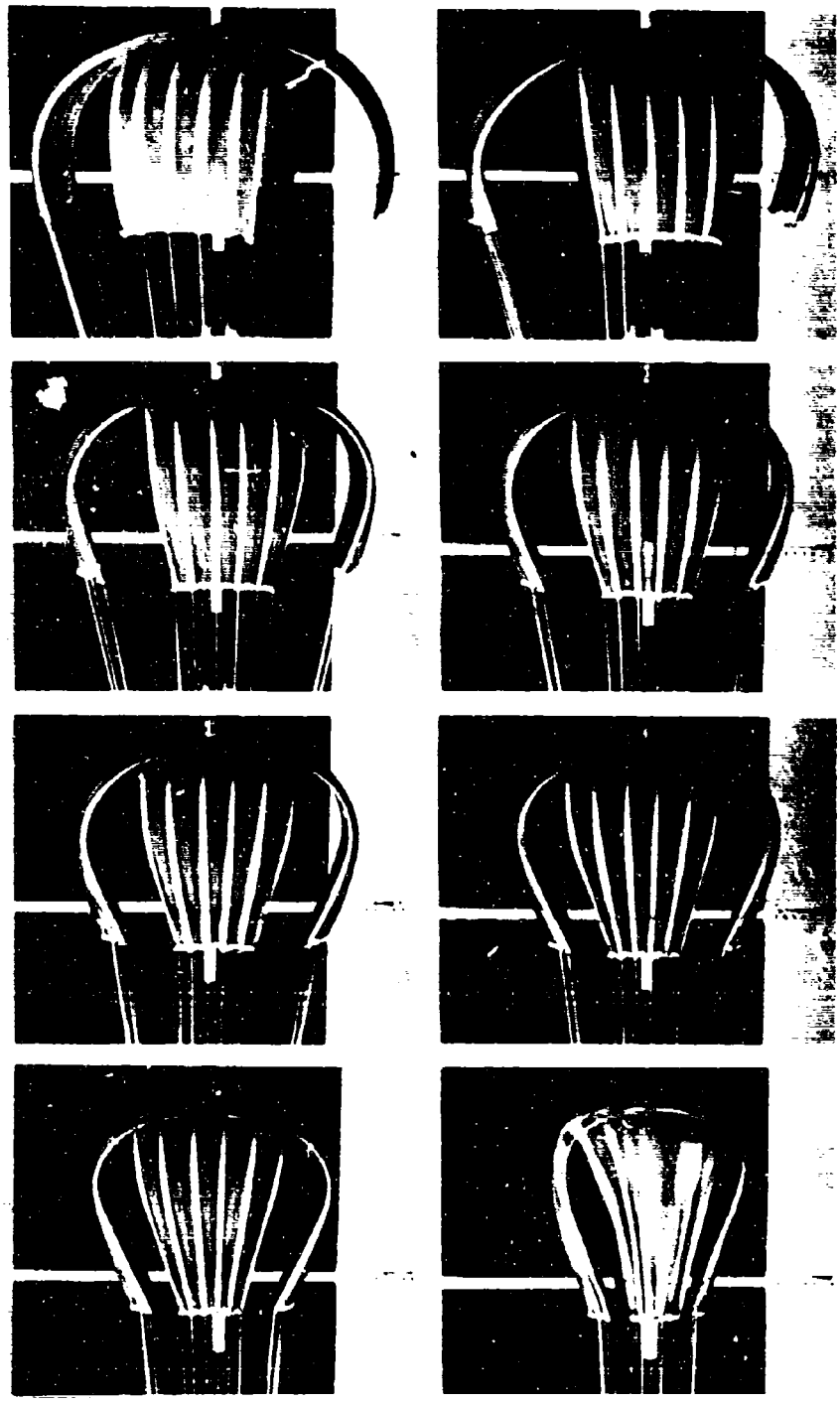

100 % REEFED
69.1 % REEFED
L/L = 1.3
55.6 % REEFED
L/L = 1.0
38.5 % REEFED
L/L = 0.7
92.6 % REEFED
L/L = 1.15
L/L = 0.85
21.0 % REEFED
L/L = 0.45

FIG. 31


100 % REEFED
93.8 % REEFED
/L = 1.6
75.7 % REEFED
/L = 1.3
67.9 % REEFED
/L = 1.15
61.1 % REEFED
/L = 1.0
54.1 % REEFED
/L = 0.85
44.5 % REEFED
/L = 0.7
26.3 % REEFED
/L = 0.45

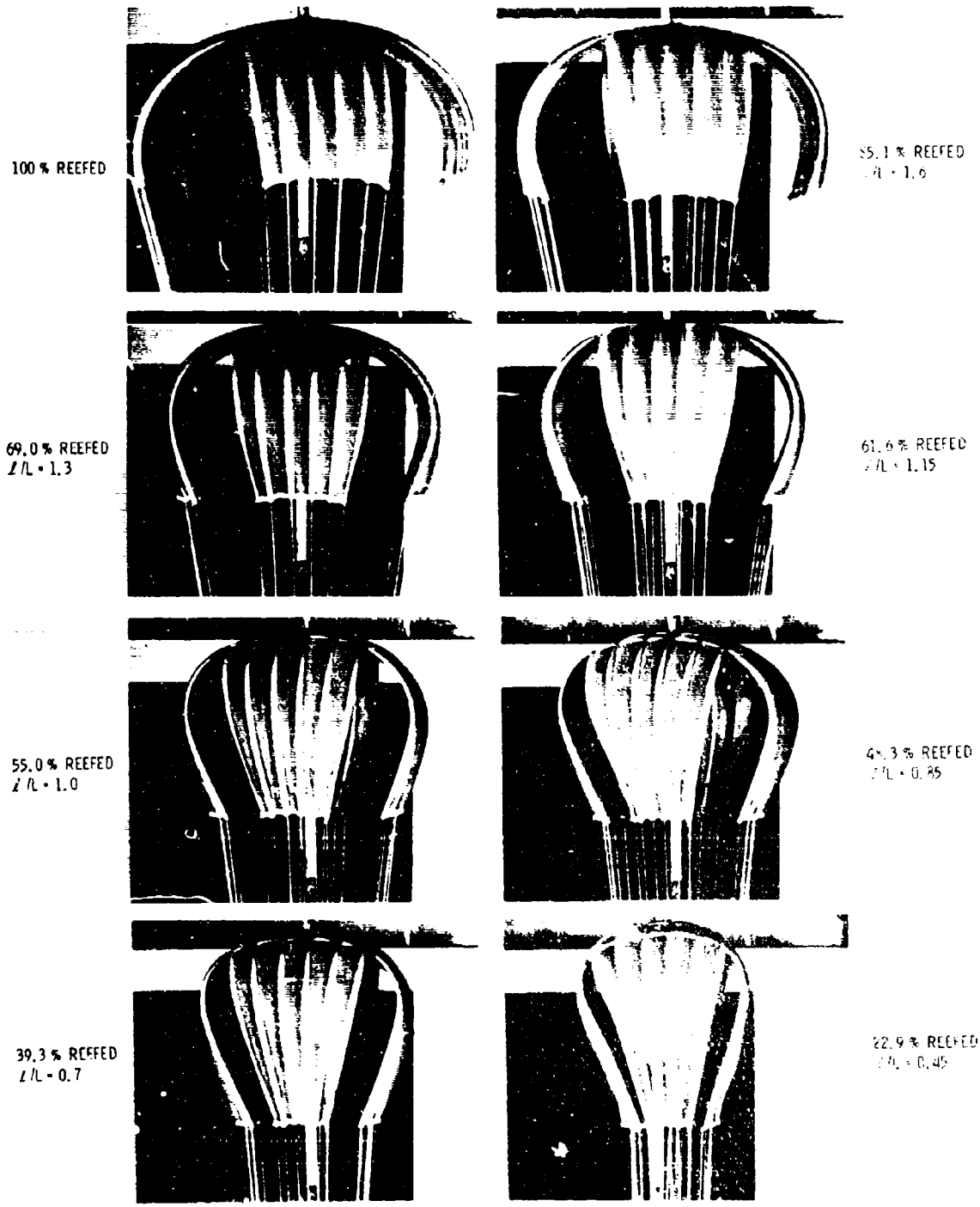


FIG. 35 REEFED CANOPY TEST PARTICULE [illegible]
F-RACHUTE SUSPENSION LINE [illegible]

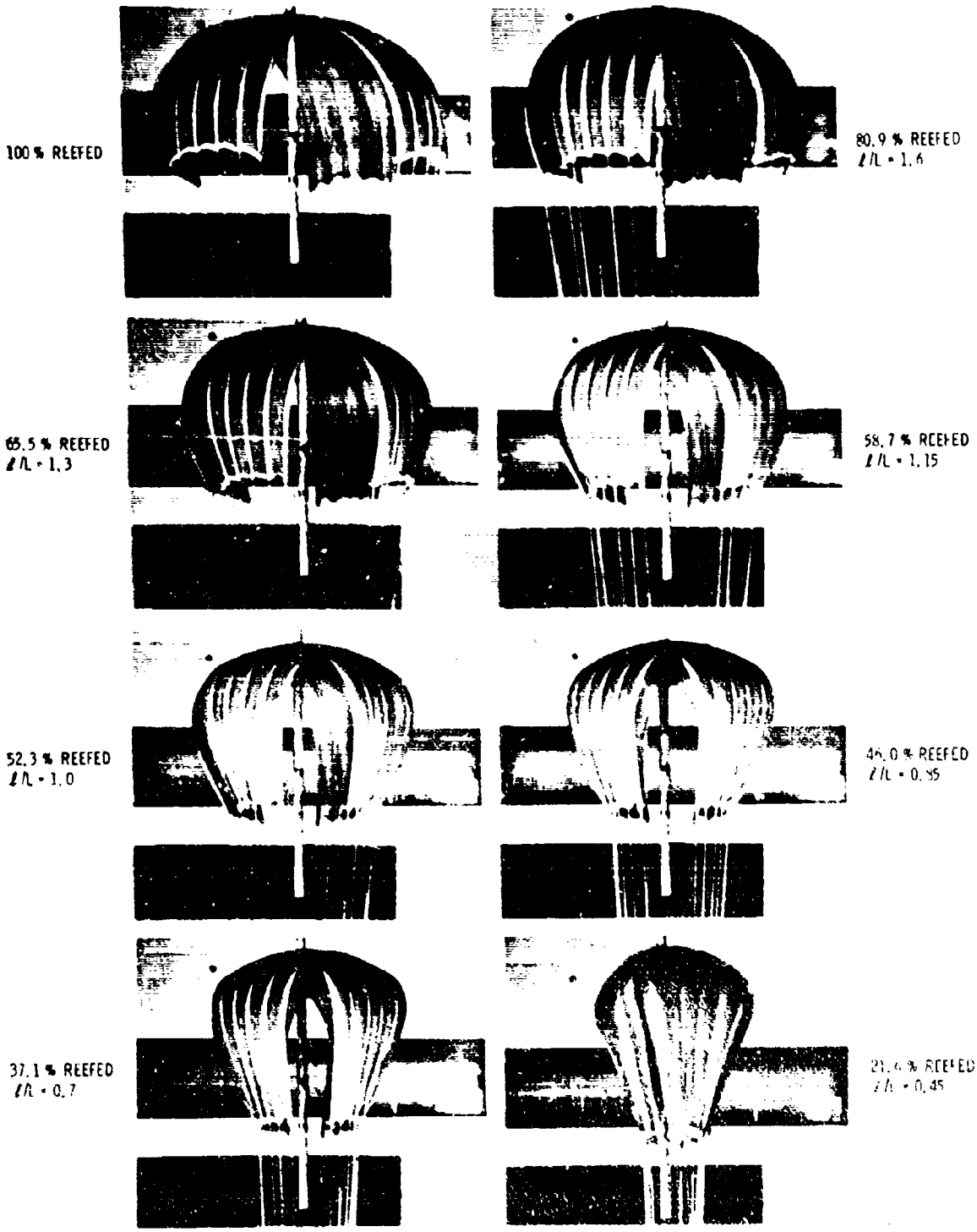
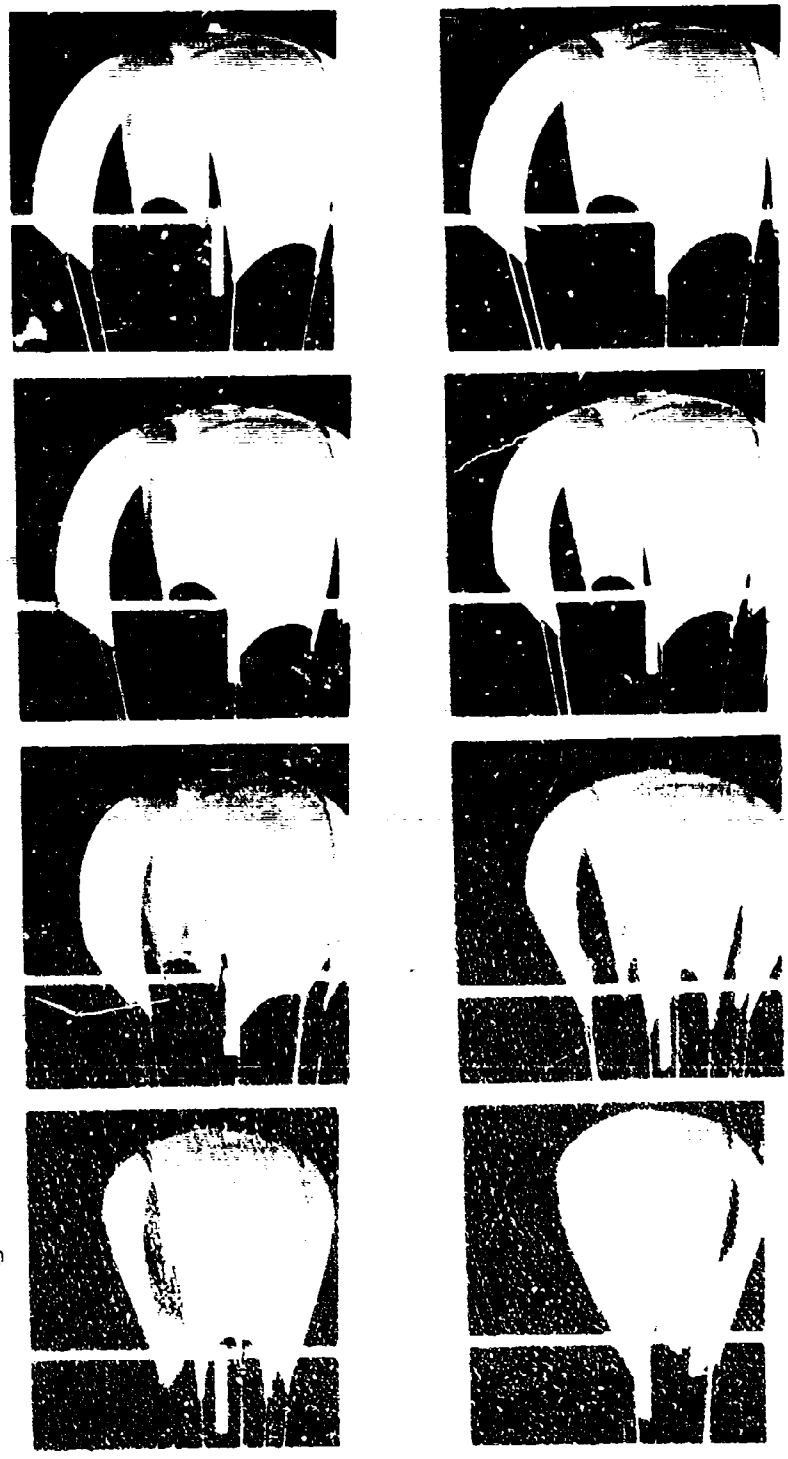


FIG. 34 REEFED CANOPY TEST, PARAMETER SERIES NO. 2, 47 SUSPENSION LINE
PARAMETER: SUSPENSION LINE LENGTH = 1.0 L, TEST VELOCITY = 215 FPS


100 % REEFED
97.8 % REEFED
ℓ/L = 1.6
87.0 % REEFED
ℓ/L = 1.3
81.1 % REEFED
ℓ/L = 1.15
70.7 % REEFED
ℓ/L = 1.00
52.7 % REEFED
40.5 % REEFED
ℓ/L = 0.7

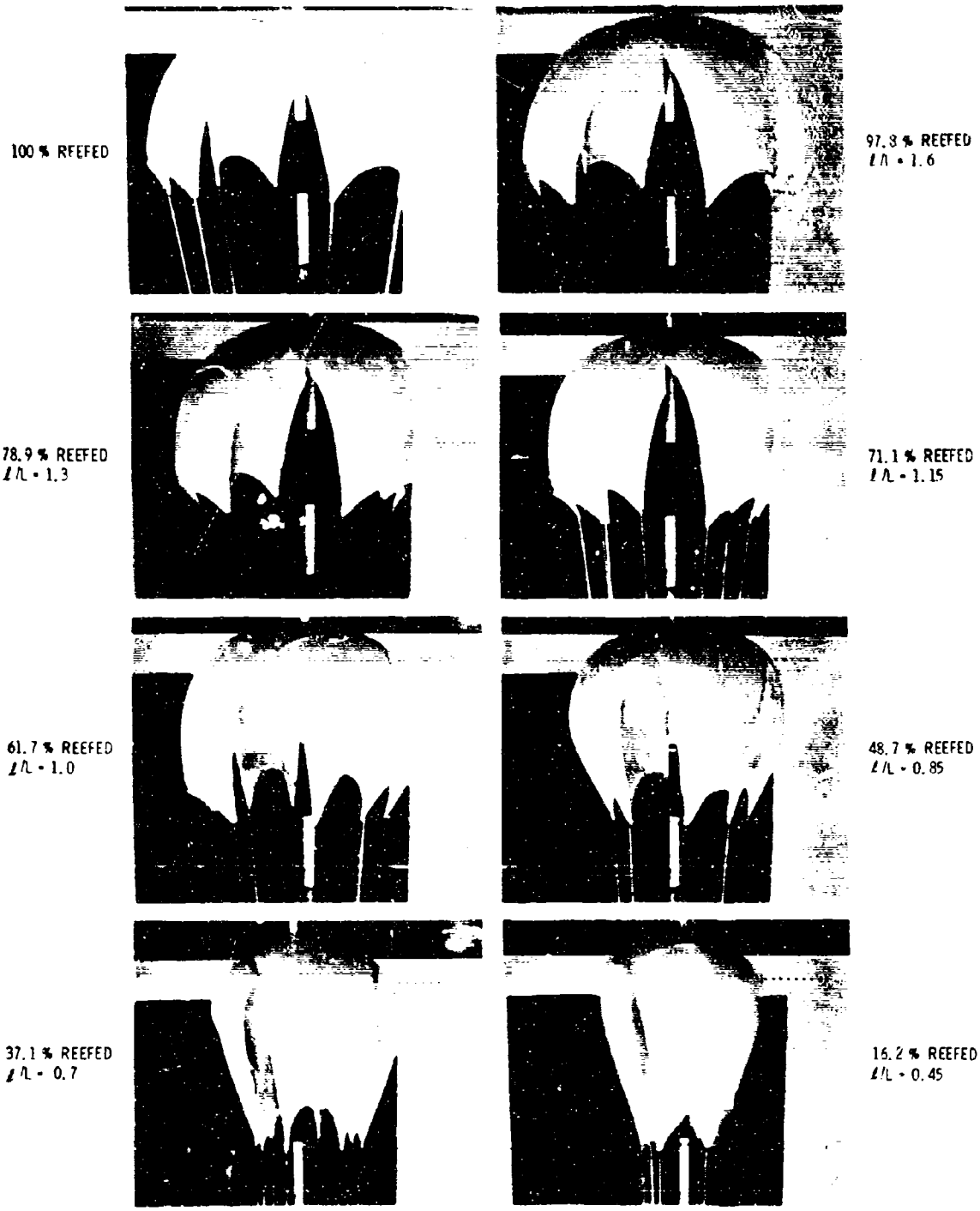


FIG. 30 REEFED CANOPY TEST: PARACHUTE SERIES NO. 9; 8 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.41; TEST VELOCITY = 275 FPS

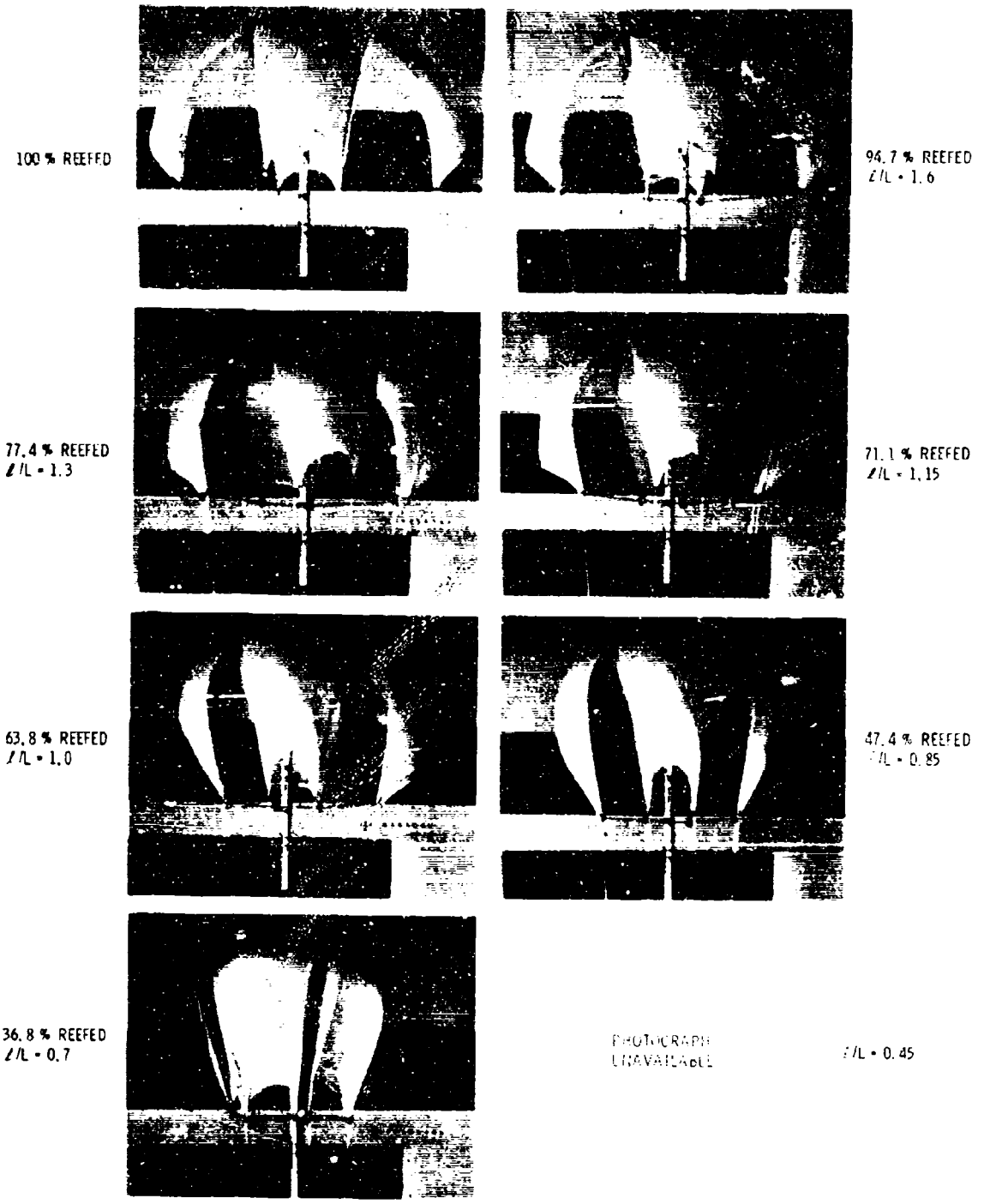


FIG. 37 REEFED CONFIG TEST PARACHUTE SERIES [illegible]
PARACHUTE SUSPENSION LINE LENGTH [illegible]

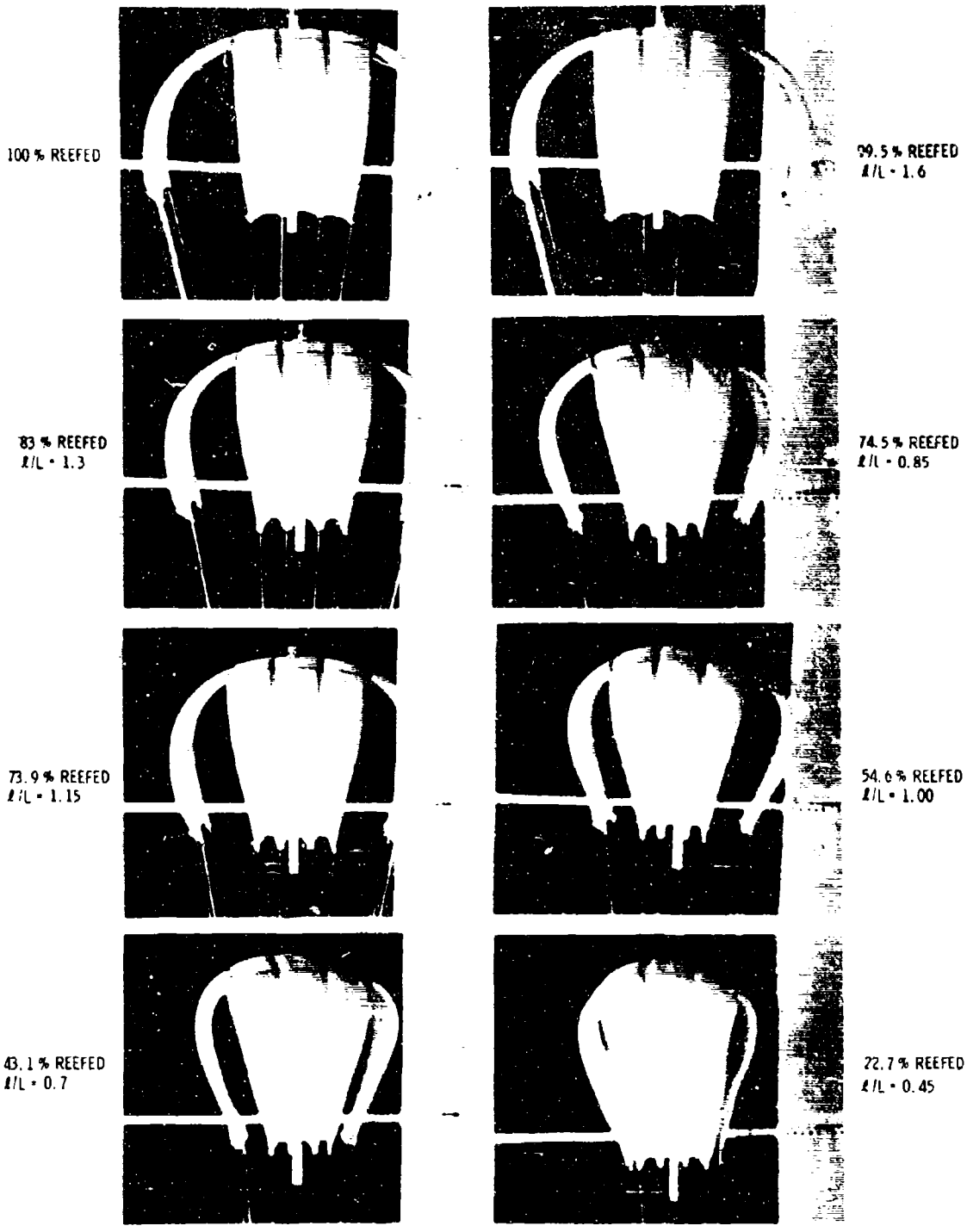


FIG. 3 REEFED CANOPY TEST, PARACHUTE SERIES NO. 3, 16 SUSPENSION LINE PARACHUTE, SUSPENSION LINE LENGTH [illegible] TEST VELOCITY = 275 FPS

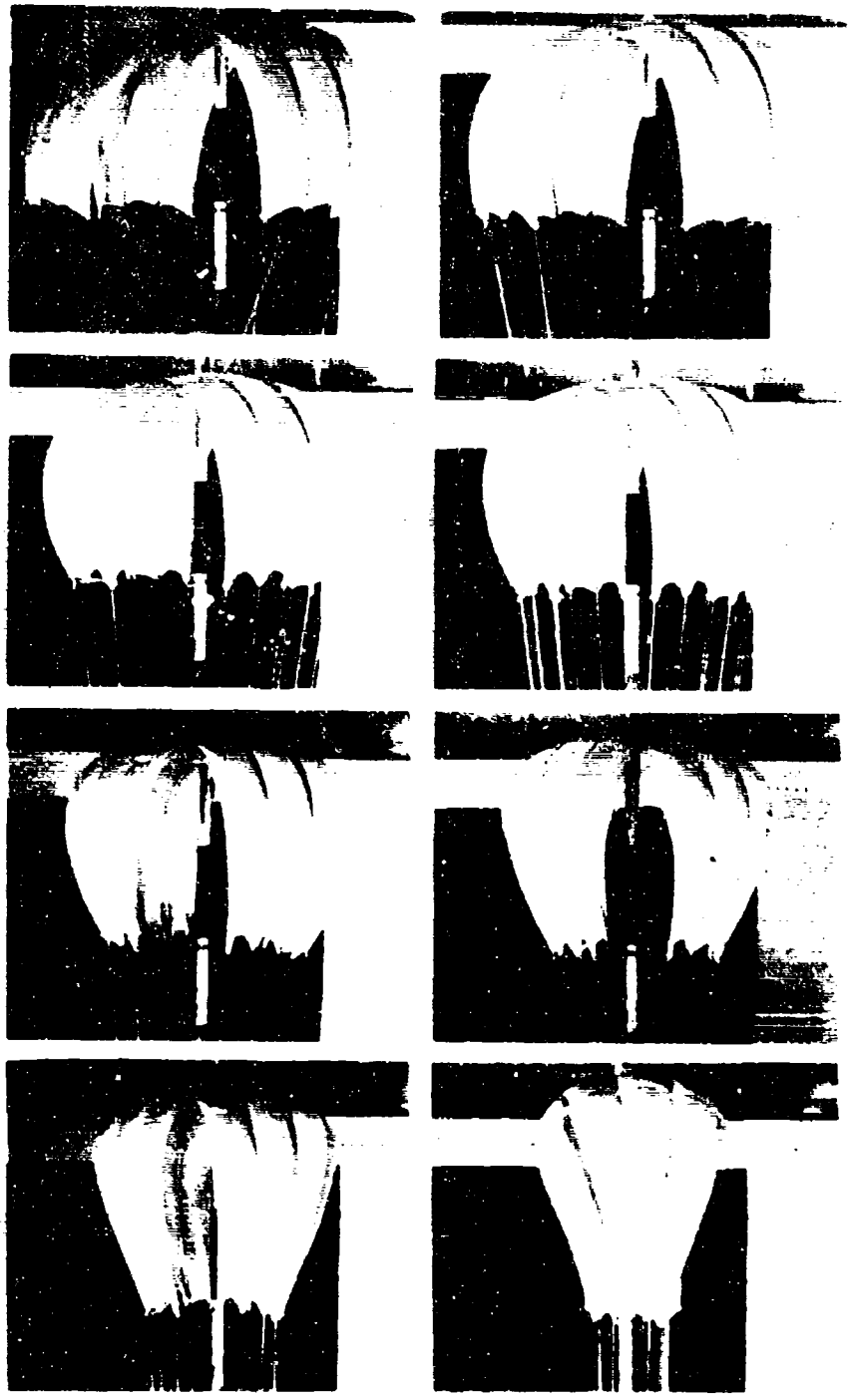


FIG. 39 REEFED CANOPY TEST; PARACHUTE SERIES NO. [illegible] SUSPENSION LINE
PARACHUTE: SUSPENSION LINE LENGTH = [illegible] TEST VELOCITY = 275 FPS

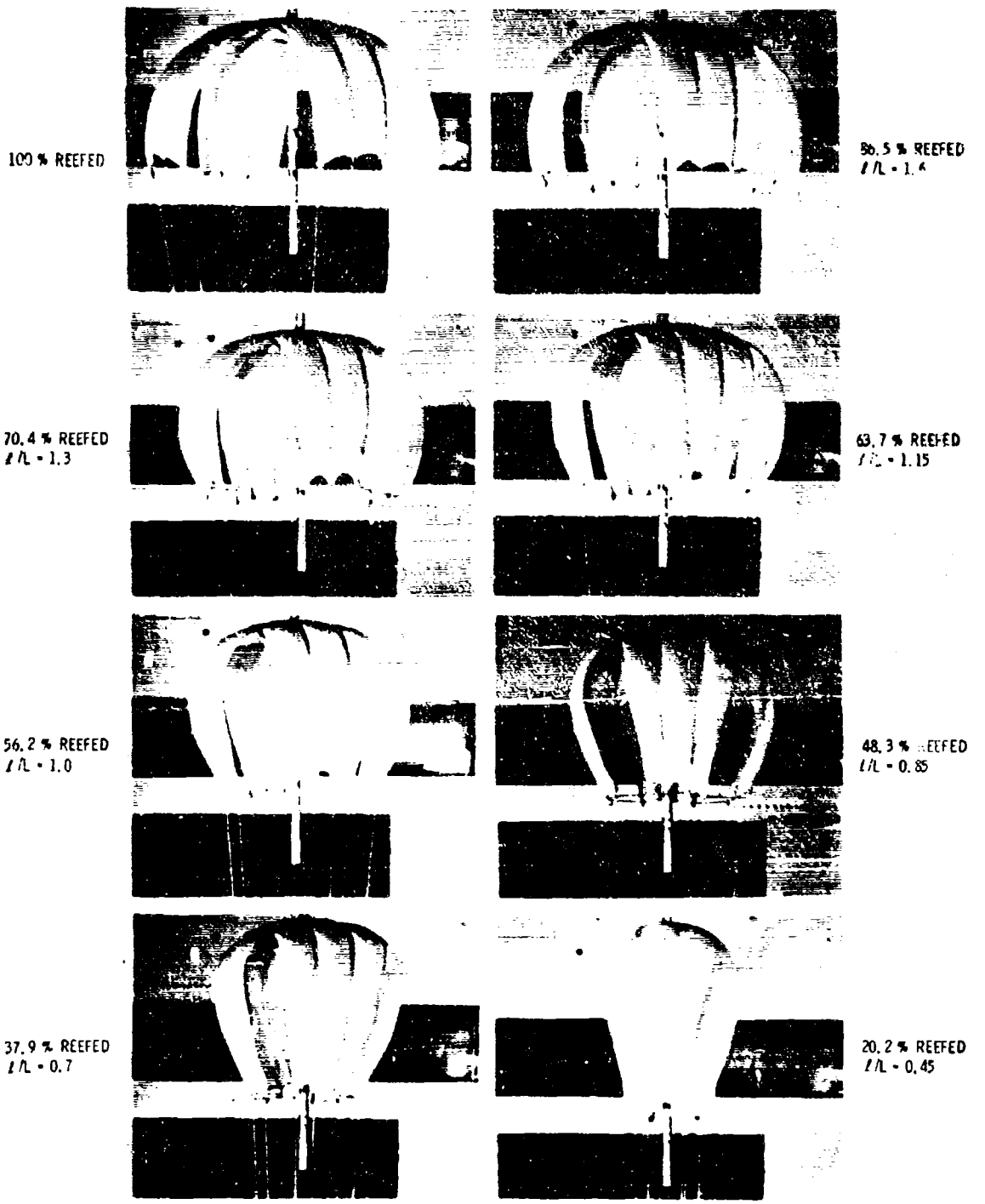


FIG. 40 REEFED CANOPY TEST; PARACHUTE SERIES NO. 4; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.8 L; TEST VELOCITY = 275 FPS

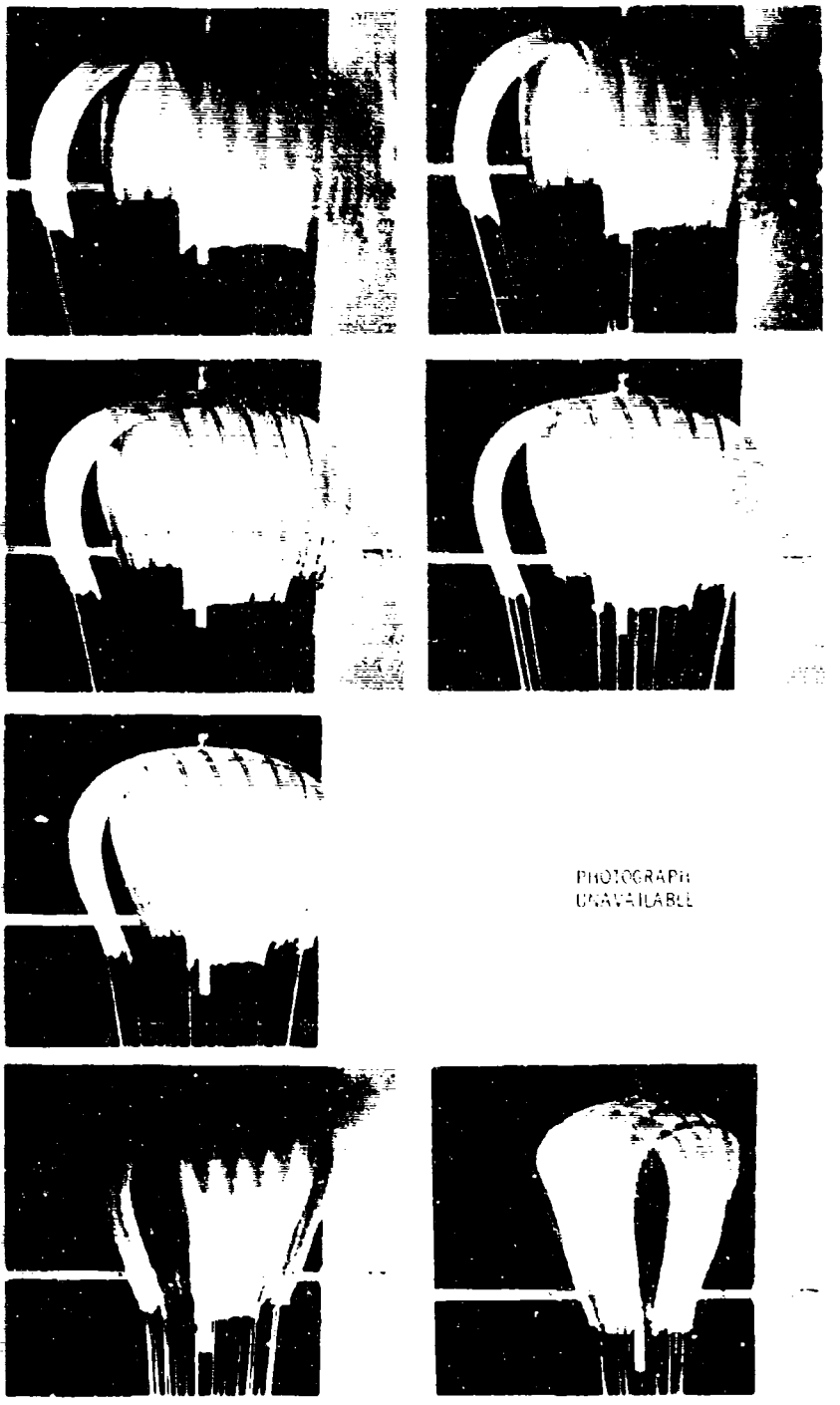


FIG. 10 REEFED CANOPY TEST; PARACHUTE SERIES NO. 3-24 SUSPENSION LINE
PARACHUTE SUSPENSION LINE LENGTH [illegible] TEST VELOCITY = 275 FPS

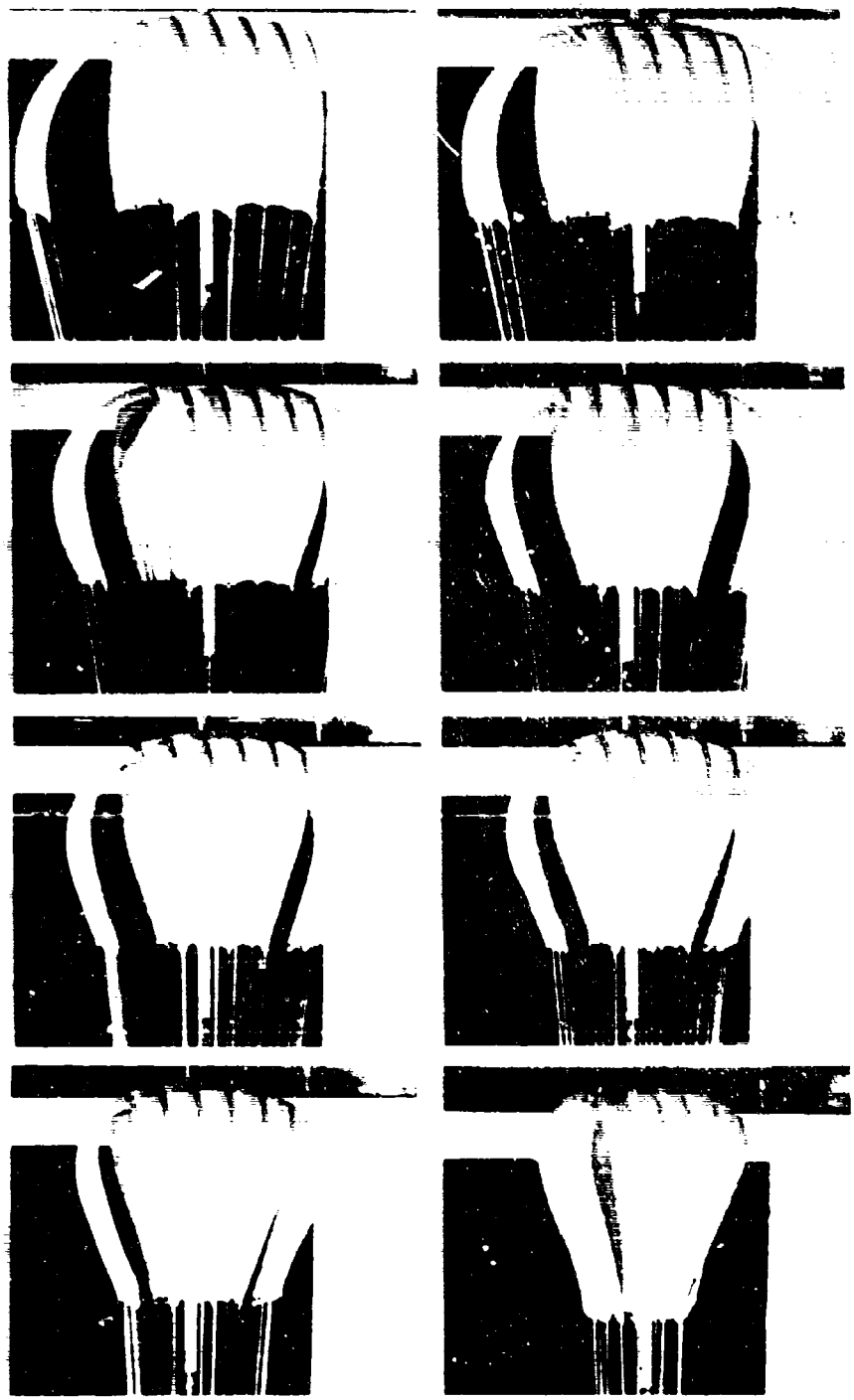


FIG. 42 REEFED CANOPY TEST: PARACHUTE SERIES NO. 24 SUSPENSION LINE
PARACHUTE SUSPENSION LINE LENGTH = 1.41 TEST VELOCITY = 275 FPS

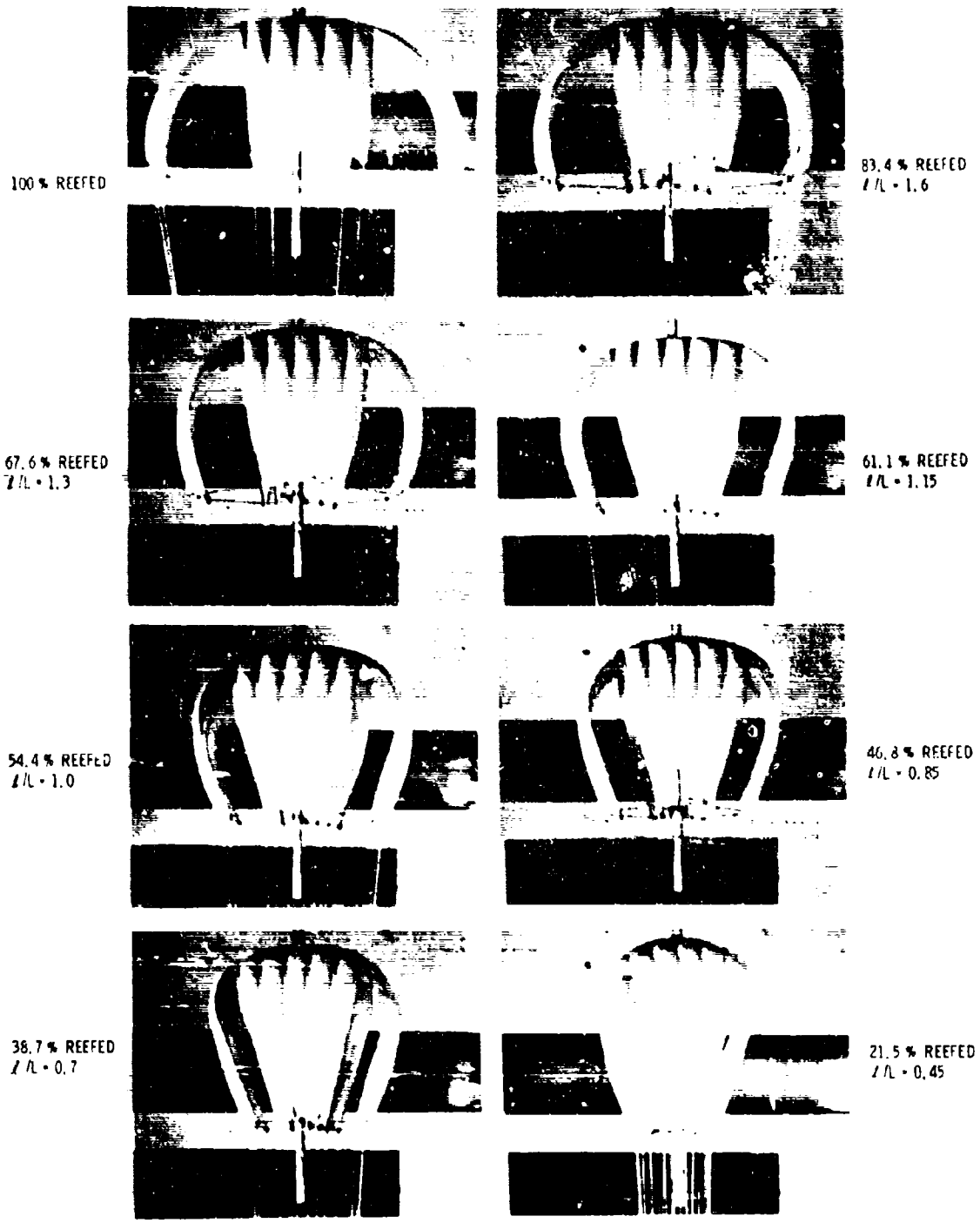


FIG. 43 REEFED CANOPY TEST; PARACHUTE SERIES NO. 3; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.5 D₀; TEST VELOCITY = 275 FPS

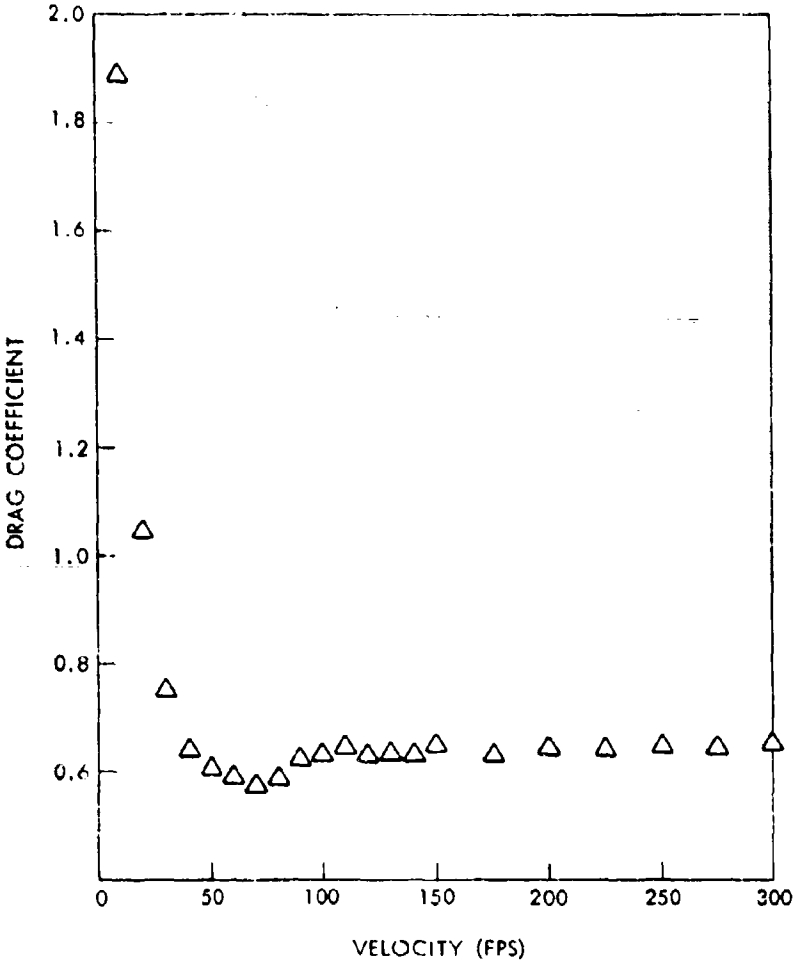


FIG. 44 DRAG COEFFICIENT TEST DATA; PARACHUTE SERIES NO. 2, 8 SUSPENSION LINES AT 1.8 L LENGTH

APPENDIX A

Initially, the investigations of the parachute drag characteristics were to encompass a velocity range from 10 fps through 300 fps. It was soon apparent that testing parachutes at very low velocities in the horizontal position resulted in unrealistic, inflated canopy shapes which cast doubts on the validity of the data. The minimum test velocity was raised to 50 fps where the inflated shape was well defined. However, one configuration, a series No. 2 parachute with 8 suspension lines of 1.8 L length, did provide acceptable data as shown in Figure 44. The sharp drag rise in the low-velocity range is evident. Similar trends were seen on other models. Tests in the low-velocity range could be conducted in a vertical wind tunnel where any changes in canopy shape will be realistic.